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汽車客運業績效評估之研究－資料包絡分析法

Evaluating Bus Transit Performance－A Data Envelopment Analysis Approach

研 究 生：范植谷

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中華民國九十三年六月

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摘要

本論文首先應用資料包絡分析法中之拋物線圖形效率測量法及方向性產出距離函數，來評量台灣汽車客運公司各車站在民營化前後利潤率及風險調整效率變化的情形，研究結果顯示，民營化後利潤率的增加可歸因於技術效率與配置效率兩者均有進步所致，惟配置效率因素所扮演的角色較為重要，而無論是公營的台汽公司或民營的國光公司都有價格扭曲的現象發生，這可能是兩家公司都試圖涵蓋無效率所導致的損失所致；其次，經整合意欲（好的）產出和非意欲（壞的）產出結果，發現台汽民營化後風險調整效率有顯著改進，而此效率改進可能係導致其成本降低的主因。

其次，因多模式汽車客運公司係台灣地區客運業之特色，此種公司同時從事不同模式（如長途客運和市區客運）的運輸服務，其特點為不同模式的服務雖使用不同的生產技術，但卻使用某些共同的投入（如管理人員），因此本論文不僅考慮多模式客運公司內部生產技術之差異，也將運輸服務的不可儲藏性（或稱產銷同時性）涵蓋在內，以便同時測量多模式客運公司的成本效率，服務效果與成本效果；由本論文所應用之多活動資料包絡分析模式與網路包絡分析模式分別與傳統模式比較發現，無論就有效率（果）的公司數，公司效率（果）排序與相互關聯效果等之評量結果顯示，兩種模式與傳統模式間有顯著性差異，且前兩者較後者更為嚴謹。

本論文之主要貢獻可歸納如下：

(一) 以往有關客運業配置效率及其相關問題之文獻甚為少見，本論文首度應用拋物線圖形效率法來評量民營化前後利潤率變化問題，這項利潤率指標可被分解為技術效率與配置效率，而配置效率則可進一步用來衡量價格扭曲的程度，此種

配置效率不同於傳統方法之處，在於它可僅需藉由觀察收入與觀察成本，而無需價格資訊即可予以衡量。

(二) 本論文首次提出將運輸風險定位為非意欲產出的觀念，應用方向性產出距離函數，整合意欲（好的）產出與非意欲（壞的）產出，用來測量民營化對風險調整效率所產生之衝擊，以有別於傳統客運業績效評估之研究，只著重在意欲產出之重大缺陷上。

(三) 台灣地區客運業，尤其老客運公司，大多屬於所謂多模式汽車客運公司，同時經營公路汽車客運及市區汽車客運，其特色為不同模式服務，係使用不同的生產技術，但卻也使用某些共同的投入，因此，亟不宜如傳統方式將其視為一整體，進行績效評比。本論文應用多模式資料包絡分析法，將共同投入合理配置至不同模式，以求得個別模式之效率值，以提供整體及個別模式之經營績效評比，以及公司內部決策之參考。

(四) 有別於傳統研究忽略運輸服務之不可儲藏性，而分開評量其三種效率（果）之缺點，本論文不僅考慮多模式客運公司內部生產技術之差異，更進一步將運輸服務的不可儲藏性（產銷同時性）涵蓋在內，並應用修正式網路包絡分析法模式將生產與消費技術納入此一模式內，以便同時測量多模式客運公司之成本效率、服務效果與成本效果，以資評比其績效差異。

Evaluating Bus Transit Performance
— A Data Envelopment Analysis Approach

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Abstract

With the aim of capturing the essence of transit performance, this dissertation addresses four crucial but often neglected issues regarding efficiency measurement for bus transit industry, and thereby using a novel refinement of conventional DEA (Data Envelopment Analysis) models to deal with these issues, in order to shed new light on the facts relevant to transit performance.

In contrast to these four issues, this dissertation consists of four essays, with particular reference to the transit performance measure in Taiwan. The first two essays pertain to the impact of privatization on bus firm's efficiency and talk about to what extent the various efficiency changes before and after privatization. The first essay applies a hyperbolic graph efficiency approach to measure "return to the dollar" at the station-level of Taiwan Motor Transport Company (TMTC) over the pre- and post- privatization period. This measure is further decomposed into its technical and allocative efficiency components. Price distortions can be measured by allocative efficiency using data on observed costs and revenues without requiring explicit information on prices.

The decomposition results indicate that both technical and allocative efficiencies contribute to the growth of "return to the dollar", with the allocative component playing a more important role than the technical component. Perhaps in an attempt to cover the

inefficiency-induced losses, both the public and private firms apparently resort to distorting relative output prices with respect to input prices, and the distortion is more pronounced in the private firm than in the public firm.

In the second essay, a directional output distance function which incorporates both desirable and undesirable outputs is employed to investigate the effects of privatization experienced by the TMTC. For the first time, the risk-adjusted efficiency change following privatization are estimated by treating transport risk as a joint but undesirable output. The empirical results demonstrate that TMTC's privatization has produced a distinct improvement in efficiency enhancement and as such may be considered to be a source of cost reduction.

The last two essays shift the focus from investigating the influence of privatization on the transit firm to the efficiency measurement of some transportation organizations which engage in various activities (services) simultaneously. This third essay focuses most attention on the technical aspect of how to determine the efficiency of individual services within different but highly homogeneous multimode transit firms which engage in their services with non-identical technologies and use shared inputs. The empirical findings indicate that the multiactivity model used is more demanding than the conventional DEA model.

The fourth essay expands the analysis of the third essay to consider both the unstorable characteristics of transportation service and the technological differences within multimode transit firms. The proposed network DEA model allows a representation of both production and consumption technologies in a unified framework and thereby can be used to simultaneously estimate the cost efficiency, the service effectiveness and the cost effectiveness of multimode transit firms. The results obtained from the network model compared to those of a conventional model are quite different in terms of the number of efficient or effective units, rank comparisons of DMUs performance as well as inter-related effects. Throughout the dissertation, the non-parametric technique, also known as DEA, is used as the common approach which integrates the four essays into a dissertation.

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Glossary of Symbols

1. Chapter 4

Notations:

x	: input vector
y	: output vector
(x, y)	: input-output vector
S	: production possibility (or technology) set
d_i	: input distance function
d_0	: output distance function
$L(y)$	: input set
$P(x)$	: output set
X	: input matrix
Y	: output matrix
N	: number of firms (DMUs)
K	: number of inputs
M	: number of outputs
u	: vector of output weights
v	: vector of input weights
ρ	: value of output distance function
δ	: value of input distance function
z	: intensity vector
θ	: efficiency score of input-orientation
ϕ	: efficiency score of output-orientation

λ : vector of constants

w_i : vector of input price

x_i^* : cost-minimizing vector of input quantities

y_i : output level

p_i : vector of output price

y_i^* : revenue-maximizing vector of output quantities

x_i : input level

2. Chapter 5

Notations:

T : graph reference set

F_g : hyperbolic graph measure

F_i : Farrell measure of input technical efficiency

F_o : Farrell measure of output technical efficiency

λ : proportional (or scaling or contraction) factor corresponding to the level of efficiency

x : input vector

y : output vector

w_s : input price

p_s : output price

O_g : overall efficiency

A_g : allocative efficiency

π : profit

π^* : maximum feasible profit

p : short-run output price

$\hat{p}$: long-run output price

w : short-run input price

$\hat{w}$: long-run input price

k' : station (DMU)

k : number of stations (DMUs)

P : number of environmental variables

N : number of inputs

M : number of outputs

Z : intensity variable

e : environmental variable

3. Chapter 6

Notations:

X : input vector

U : output vector

$P(X)$: output set

y : good(s)

b : bad(s)

D_0 : directional output distance function

4. Chapter 7

Notations:

x : input vector

y : output vector

$p(x)$: output set

M : number of inputs associated soly with HB

Q : number of outputs associated soly with HB

R : number of outputs associated soly with UB

α : positive constant associated with the HB or UB production process

θ : efficiency score

w : priority given to HB or UB

Superscripts:

H : input associated with highway bus service (HB)

U : input associated with urban bus service (UB)

S : input associated in part with HB and in part with UB

E : environmental factors

Subscripts:

d : driver

v : vehicle

f : fuel

l : network length

t : mechanics

k : firm (DMU)

z : long-haul transportation demand

s : short-haul transportation demand

5. Chapter 8

Notations:

X	: input vector
Y	: output vector
x	: shared input
u	: the proportion of the shared inputs assigned to each service
α_d	: the proportion of the shared inputs assigned to each service or consumption process
n	: number of firms (DMUs)
A	: production possibility set
$P(y)$	: input set
$P(x)$	: output set
λ	: intensity vector
θ	: efficiency score
w	: the priority given to the two service and processes
$\vec{D}$	: general form of directional distance function

Superscripts:

PH	: input soly associated with HB
PU	: input soly associated with UB
PC	: inputs contribute to both HB and UB
C	: inputs soly associated with the consumption process
PCC	: inputs contribute to HB, UB and consumption process
E	: environmental factor

Subscripts:

k : firm (DMU)

d : driver

f : fuel

v : vehicle

l : network length

t : technical (mechanics)

c : car ownership

p : population density

s : sale staff

m : management labor

h : veh-kms or pass-kms

u : frequencies of service or passengers

a, b, c, d, e : input items

$f \cdot g$: intermediate output items

z, o : final output items

CHAPTER 1

Introduction

This dissertation is composed of four essays which deal with four crucial but often neglected issues concerning transit performance, with particular reference to Taiwanese bus transit industry. The first two essays pertain to the impact of privatization on bus firm's efficiency and talk about to what extent the various efficiencies or effcetivenesses change before and after privatization. The first essay measure the "return to the dollar" (profitability, profit margin), technical efficiency (TE) and allocative efficiency (AE), and thereby estimating price distortions at the station-level of Taiwan Motor Transport Company (TMTC) over the pre- and post- privatization period, so as to explore the effects of privatization on the transit firm.

In the second essay, both desirable and undesirable outputs are incorporated in the model to investigate the effects of privatization experienced by a transit firm. For the first time, the risk-adjusted efficiency changes following privatization is estimated by treating transport risk as a joint but undesirable output.

The last two essays shift the focus from investigating the influence of privatization on the transit firm to the efficiency measurement of some transportation organizations which engage in various activities (services) simultaneously, such as multimode bus transit. The third essay focuse on the technical aspect of how to determine the efficiency of individual services within different but highly homogeneous multimode transit firms which engage in their services with non-identical technologies and use shared inputs.

The fourth essay expands the analysis of the third essay to consider both the unstorable characteristics of transportation service and the technological differences within multimode transit firms in efficiency and effectiveness measurement. The proposed DEA model differs from conventional models in two respects: First, the consumed services occurring concurrently with the produced services are explicitly taken into account, and second, the model allows a representation of both production and consumption technologies in a unified framework and thereby can be used to simultaneously estimate the cost efficiency, the service effectiveness and the cost effectiveness of multimode transit firms.

This chapter gives an overview of the motivation and problem statement, research objectives and study approaches, as well as depicts the framework of this dissertation.

1.1 Motivation and problem statement

The 1996 new legislation concerning the partial deregulation of bus industry led to a major structural change in the whole industry in Taiwan and provide a new framework for all bus operation (as will be seen below in Chapter 2). This dissertation intends to study the impacts of privatization and regulatory changes in the public transport industry, with special reference to efficiency and/or effectiveness measurement. On one hand, the TMTC's privatization programme offers a unique opportunity to analyze the effects on the efficiency change of its kind. On the other hand, except a few cases, most of long established operators, so-called multimode transit firms, seem to have worked effectively and have still survived following deregulation. Therefore there is a requirement to examine carefully transit performance based on the concepts of efficiency and/or effectiveness.

The study of TMTC's privatization is of particular interest in several respects. First, it is especially unfortunate that few frontier studies have focused on the effects of privatization and regulatory changes in the public transport industry (De Borger et al., 2002). Second, it has been the first privatization case through employee buy-out (EBO) since the beginning of Taiwanese government's privatization programs in 1989. The combination of the direct employee shareholding in buy-out and a sector where individual skills are important may be expected to generate significant effects on performance (Wright et al., 1992). Third, TMTC has been facing long-term financial difficulties due mainly to its inefficiency since 1988. The most notable have focused on the after-effects of transferring to the private sector, that is, whether the newly privatized firm Kuo Kuang Motor Transport Company (KKTC) is capable of improving this situation or is quickly driven out of market. Fourth, the economic literature that deals with the existence of employee-owned firms has paid little attention to EBOs (Bonnie and Putterman, 1987; Bonnie et al., 1993). And lastly, as an important case study, the comparison of TMTC's performance before and after privatization provides new empirical evidence and theoretical extension on the property right theory, focusing upon the privatization of the Taiwanese bus industry. Therefore, the TMTC’s privatization program offers a unique opportunity to analyze the effects on the performance of its kind.

On the other hand, despite the transit sector has been experiencing declining ridership in the early 1990s, bus transit remains an important mode in Taiwan. Bus transit systems are, therefore, increasingly under pressure to improve their performance, both from the point of view of technical and allocative efficiencies as they yield complementary information about the management effectiveness of an individual bus firm. Technical efficiency has a diagnostic purpose as it yields comparative information about the effectiveness with which individual units convert their input resource into outputs. On the other hand, allocative efficiency has a planning orientation since the objective of assessment is to gauge efficiency improvements by means of resource reallocation. However, most of the extant literature on performance measurement for transit firms restrict their analyses to the use of technical efficiency (see e.g., Gathon 1989; Chang and Kao 1992; Fazioli et al. 1993; Obeng, 1994; Bhattacharyya et al. 1995; Sakano et al. 1997; Costa 1998; Lijesen 1998; Cowie and Asenove 1999; Kerstens 1999; Nolan et al. 2002; Odeck 2003; Karlaftis 2004).

The reasons for studying technical efficiency stem from several factors. Allocative efficiency calculation requires input prices (Lovell, 1993). The data needed for this calculation were not readily available. Allocative efficiency assumes that firms are cost minimizing (Viton, 1995). This assumption may not be valid for the urban transit industry. As indicated by some literature, transit firms have a variety of goals, including but not limited to cost minimization. The second reason for choosing technical efficiency is that it provides some insight into underlying research issues such as how economies of scale and density of the urban center relate to transit efficiency. From efficiency scores one can judge whether a firm is using its inputs in the most productive way relative to the sampled firms (Labrecque, 1996).

However, the lack of published research on combining technical efficiency and allocative efficiency measures of performance and thereby measuring further price distortions in the bus transit market places a limit on our understanding of production processes, or even market mechanism. In light of this, a novel approach leads to a derivation of an allocative efficiency index, which measures price distortions using data on observed costs and revenues without requiring explicit information on prices is clearly needed to deal with this problem, under the assumption of cost minimization.

As indicated by Tomazinis (1975), one of the major problem in productivity studies of a social system (such as a transportation system) is based on the handling of undesirable (bad) outputs of the process. All desirable (good) inputs can be added of course, either as physical units or on the basis of their market prices. Undesirable outputs, however, are negative by-products with no market value. If such undesirable by-products are left alone (not sold and not requiring any cost for their disposal), as has been the case for air pollution for many years, the undesirable outputs do not enter any productivity analysis of the production process. In case special costs are required for the treatment or disposal of such undesirable by-products, their cost should enter somewhere in the productivity analysis.

From many points of view the most effective treatment of this issue would be to include the additional costs as part of the production process of the desirable output itself. In other words, when evaluating the performance of producers it makes sense to credit them for their provision of desirable outputs and penalize them for their provision of undesirable outputs. That is to say, “goods” and “bads” should be treated asymmetrically in gauging producer performance. In fact, most currently available performance measures do treat the two asymmetrically, by valuing goods and ignoring bads (Fare et al. 1989).

On the other hand, due to the development of frontier methods for the study of efficiency there is a large strain of literature on the efficiency of bus transportation. Moreover, a comprehensive survey of frontier methodologies and empirical results for public transit has been presented by De Borger et al. (2002). Relevant performance indicators and the methods to measure them have been reviewed. The existing frontier studies measuring transit performance have also been systematically summarized and critically assessed (see e.g., Chang and Kao, 1992; Chu et al., 1992; Bhattacharyya et al., 1995; Viton, 1997; Cowie and Asenova, 1999; Nolan et al. 2002).

Most of these previous research studies on measuring firms’ efficiency and productivity are typically conducted without taking into account undesirable outputs which may not be freely or costlessly disposable.

Accidents of all kinds are an inescapable part of bus operations, however much one seeks to avoid them. Inevitably, they involve insurance procedures and very often the intervention of police; perhaps even court proceedings of one kind or another. The manager of a bus firm will have clear duties in the case of an accident within his area of responsibility (Hibbs, 1985). In other words, transportation safety has bee paramount issue, due mainly to producers (operators), consumers, and policy makers have paid increasing attention to the safety performance of bus transport. Operators no longer consider the transport risks as a secondary concern of the service produced.

One component of the public debate on the competitiveness of transport services has focused on the role of transportation safety. In fact, the reputation for safety has been one of the key qualities of transportation that contribute to market segment. Such opportunities are regarded as a “win-win” situation, because business and social goals are both met. Many public policy efforts seek to identify and eliminate the production inefficiency that prevents simultaneous improvements in both efficiency and transportation safety. Whether these types of public policy initiatives are successful depends on the extent to which such inefficiencies are widespread in transport services, especially in intercity bus services. There is a requirement to measure the magnitude of these “double wins” opportunities where transport risks can be reduced with efficiency improved concurrently among a set of DMUs producing bus services. This may help both operators and policy makers to set up their targets to reduce the inefficiencies.

Improved efficiency will, *ceteris paribus*, reduce cost, boost transit ridership, as well as reduce the need to subsidize the transit systems, and hence it has been widely held to be one of the principal objectives in most transportation organizations. In light of this, it is an appropriate way to measure and compare performance with peer groups, in particular reference to the efficient use of resources.

Some transportation organizations engage in various activities (services) simultaneously; for example, an airline, railway, or marine company may simultaneously provide passenger, freight, and other services respectively. Another famous example could be a public transit company, which involves various transportation modes simultaneously. On the other hand, for a variety of applications to which DEA could be applied, there is often a shared resource (or cost) which is imposed on some (or all) decision making units (DMUs, refer to transit firms here).

A problem then arises with respect to how this resource (or cost) can be assigned in an equitable or optimal way to the various DMUs. Few DEA studies relating to multimode transit agencies deal with the shared input problem in a proper way. For example, Viton (1997, 1998) analyzed the efficiency of U.S. multimode bus transit systems operating conventional motor-bus (MB) and demand-responsive (DR) services using DEA. However, the allocation problems of the system costs data appear to have been ignored.

Clearly, the allocation problem of shared inputs need to be considered and dealt with properly, and thereby estimating the efficiency or effectiveness of transportation organizations that engage in several services simultaneously. DMUs in this situation may have some inputs and outputs among all the services, and in doing so, estimate the efficiency or effectiveness with a given organization carries out each activity.

A wide variety of methods can be derived for measuring performance based on the concepts of efficiency and effectiveness. However, while evaluating transit performance it is worth noting that, unlike the production and consumption processes of the manufacturing sectors a transit service cannot be stored, and therefore the output consumed or the final output produced, such as passenger-kms may vary considerably from the output produced or the intermediate output, such as vehicle-kms, in a transit system. Specifically, the consumed services occur concurrently with the produced services, If the final output is not consumed simultaneously with the intermediate output, it is lost (Tomazinis, 1975). This perishability of the commodity produced, and the fact that only a proportion of the services produced are actually consumed is often neglected in transit performance measures (see for example, De Borger et al., 2002). If these unique unstorable characteristics of transit services are justified, then it is vitally important to obtain valid estimates of transit performance. These estimates must be obtained by combining the cost efficiency measure, service effectiveness measure and cost effectiveness measure into a single model, taking into account explicit modeling of produced services and consumed services inside the technology.

In addition, as indicated by Beasley (2003), organizations of any complexity typically consist of a number of individually identifiable units. For example, within a transit firm these units may correspond to different transit services. Such units are linked at the company level in the way of allocating resources (such as management and sales staff) to individual units.

The total amount of resources that the firm can allocate will be limited. This problem is plainly important in a number of transit firms. It is currently, for the most part, dealt with through a mixture of standard accounting approaches and negotiations between individual services and the organization, or even ignored (see Vition 1997,1998). To estimate the efficiency and effectiveness achieved by multimode transit firms with the two production functions using shared inputs, a specific model needs to be developed and incorporated into aforementioned single model, so as to solve these problems mentioned above.

1.2 Research objectives

Based on the motivation and problem statement mentioned in previous section and with the aim of capturing the essence of transit performance, this dissertation has addressed four crucial but often neglected issues regarding efficiency measurement for bus transit industry, and thereby using a novel refinement of conventional DEA models to deal with these issues, in order to shed new light on the facts relevant to transit performance. Specifically, the following research objectives corresponding to four essays are presented in this dissertation, respectively.

1. Aside from describing the operating changes of the TMTC and the KKTC response to privatization which ultimately resulted in a profit change in the KKTC, the first essay seeks to identify two critical issue. First, whether or not technical efficiency improved following privatization? And second, to what extent price distortions were created in the transportation market under each ownership type before and after privatization?
2. To evaluate the after-effects of privatization on the KKTC's performance, the second essay intends to employ a model which allows to consider both the desirable production output, “good”, and the undesirable production output, “bad”, and to

assess the level of production inefficiency that gives rise to opportunities in improving efficiency and overall performance simultaneously. In addition, transport risk will be treated as a joint but undesirable output while measuring the risk-adjusted efficiency. Ideally, this may help both operators and policy makers to set up their targets to reduce the inefficiency.

3. The third essay is to measure and compare performance of 24 multimode transit firms with peer groups, focusing most attention to how the shared input resources can be assigned in an equitable or optimal way to the various DMUs which engage in their services with non-identical technologies and use shared inputs. This will permit the operators to discover, understand and illuminated accurately the situation at any given moment and the reasons behind any overall system rating.
4. To fill a void in the literature, the fourth essay tries to propose a model that allows a representation of both production and consumption technologies in a unified framework, and hence can be used to simultaneously estimate the cost efficiency, service effectiveness and cost effectiveness of multimode transit firms which carry out their services with non-identical technologies using common inputs.

1.3 Study approach

To reach various aforementioned research objectives, the study approaches used in this dissertation are specified as follows.

Fare et al. (2002) establish the relations between hyperbolic graph measure of technical efficiency and the radial measures of technical efficiency and show the dual cost and revenue interpretation of the hyperbolic efficiency measure are related to Georgescu-Roegen’s (1951) notion of “ Return to the dollar”. Once this relation is established, it leads to a derivation of an allocative efficiency index, and thereby measuring the price distortions in the transportation market.

The first essay is to apply a hyperbolic graph efficiency approach to measure “return to the dollar” at the station-level of TMTC before and after privatization. The “return to the dollar” measure is decomposed into two components: a technical efficiency index and an allocative efficiency index. Moreover, price distortions are measured by allocative efficiency which uses data on observed costs and revenues without requiring explicit information on prices.

A directional distance function which incorporates both desirable and undesirable outputs is employed in the second essay to investigate the impact of privatization experienced by the TMTC. For the first time, transport risk is treated as a joint but undesirable output to measure efficiency changes following privatization. More specifically, the directional distance function allows for considering both the desirable production output, “goods”, and the undesirable production output, “bads”, so as to measure the linkage between “goods” and “bads” and to assess the level of production inefficiency and overall risk-adjusted efficiency simultaneously. Following Fare et al. (1998), the current study defines measures that allow desirable and undesirable production to vary by the same proportion, but desirable outputs are proportionally increased while undesirable ones are simultaneously decreased. The essence of the method is to compute the opportunity cost of transforming the production process from one where all outputs are strongly disposable to one which is characterized by a weak disposability of undesirable outputs.

A number of studies have been presented recently, both from a practical organizational standpoint and from a costs research perspective, to deal with the shared inputs problem (see for example, Golany,1993; Golany and Tamir, 1995; Beasley, 1995, 2003; Mar Molinero, 1996; Thanassoulis, 1996, 1998; Fare et al, 1997; Fare and Grosskopf, 2002; Mar Molinero and Tsai, 1997; Tsai and Mar Molinero, 1998, 2002). Among them, the multiactivity DEA model, a novel refinement of the conventional DEA approaches, for the joint determination of efficiencies in the DEA context, was proposed by Beasley (1995) and subsequently revised by

Mar Molinero (1996). Tasi and Mar Molinero (1998, 2002) evaluated efficiencies of organizations that engage in several activities simultaneously. DMUs in this situation may have some inputs and outputs among all the activities, and in doing so, estimate the efficiency with which a given organization carries out each activity.

In the third essay of the dissertation, the multiactivity DEA model is applied to explore the efficiency of individual services within different but highly homogeneous multimode transit firms in Taiwan, due to its being designed, in particular, to estimate the efficiency achieved by organizations which face several production functions using shared inputs.

Following Fare and Grosskopf (1996, 2002), the fourth essay presents an approach to include both the unstorable characteristics of transportation service and the technological differences within multimode transit firms in efficiency and effectiveness measurement. The proposed network DEA model differs from conventional models in two respects: First, the consumed services occurring concurrently with the produced services are explicitly taken into account, and second, the network model allows a representation of both production and consumption technologies in a unified framework and hence can be used to simultaneously esitimate the cost efficiency, the service effectiveness and the cost effectiveness of multimode transit firms which carry out their services with non-identical technologies and use shared inputs.

The proposed network DEA model is applied to production and consumption data for a sample of multimode bus transit firms in Taiwan. Of the 60 bus companies in Taiwan, 24 of them operated both highway bus services (HB) and urban bus services (UB) in 2001.

1.4 Framework of the dissertation

The rest of the dissertation will be organized as follows:

Chapter 2 will introduce a brief background of Taiwanese bus transit sector. In section 2.1, the deregulation feature in Taiwan will be presented. Changes to the structure of the bus industry after deregulation will be addressed in section 2.2. Market shares by ownership types of highway bus operator will be discussed in section 2.3. Section 2.4 will report the privatization of Taiwan Motor Transport Company.

Chapter 3 will review relevant literature in four respects: First, frontier studies of transit systems, these include those use either parametric approach (mainly stochastic frontier approach, SFA) or non-parametric approach (mainly DEA) or both, respectively. Frontier studies in Taiwan will also be briefly reviewed in contrast to the current study. Then, the wide variability in the use of input and output measures in transit will be presented. Second, related studies concerning transit performance which are applied in this study will be introduced. Third, related studies of transit privatization will be outlined. And lastly, limitations of previous study will be discussed.

Chapter 4 will introduce the basic DEA model as a starting-point for the methodologies used in this dissertation. The introduction will center on comparing the DEA with SFA, both have been used widely in the measurement and estimation of efficiency. The chapter will present comparison results which led to the methodological choice of this study, the DEA approach. And this will be followed by a series of discussions concerning the concepts of basic DEA model, including distance function, efficiency measurement, technical efficiency and allocative efficiency, as well as environmental variables used in DEA analysis.

Case studies will be provided in each of Chapters 5 to 8 to illustrate the application of both the applied and proposed models and to demononstrate these model's effectiveness. Chapter 5 will use hyperbolic graph efficiency approach to measure "return to the dollar" before and after TMTC's privatization. The "return to the dollar" will be further decomposed into a technical efficiency index and an allocative efficiency index, and thereby estimating price distortions in the transportation market.

Chapter 6 employs a directional distance function which incorporates both desirable and undesirable outputs to investigate the effects of privatization experienced by the TMTC. By treating transport risk as a joint but undesirable output, the overall risk-adjusted efficiency changes following privatization will be estimated.

Chapter 7 will focus most attention on the technical aspect of how to determine the efficiency of individual services within different but highly homogeneous multimode transit firms which engage in their services with non-identical technologies and use shared inputs.

Chapter 8 will expand the analysis of the last case to consider both the unstorable characteristics of transportation service and the technological differences within multimode transit firms in efficiency and effectiveness measurement. The proposed network DEA model will demonstrate its being more demanding than the conventional DEA model. The last chapter (Chapter 9) will outline the contribution to the literature, summary, policy implications of the dissertation, as well as area for further research.

CHAPTER 2

An Overview of Taiwanese Bus Transit Sector

The 1996 new legislation concerning the partial deregulation of bus industry re-organized the whole industry in Taiwan and provided a new framework for all bus operations. It symbolized the most radial change given that it represented a departure from a status quo of nearly 50 years standing. This chapter intends to report briefly deregulation feature first, followed by the new structure of the bus industry, and an overview of privatization of the Taiwan Motor Transport Company.

2.1 Deregulation feature

The term “regulation” concerning bus industry in Taiwan covers a number of aspects which are almost the same as those in Great Britain prior to 1980.

This first is entry and exit control, an operator is not at liberty to enter (or leave) the bus market at will. According to the Road Traffic Act 1984, a road service licence ratified by the relevant area licensing authority, such as the traffic commissioners, is required for a new entrant to enter the market to operate new services. The Act also contains an obligation upon operators to report the authority of the intention to cease operation in advance. The incumbent operator was not allowed to leave the market without the permission of the relevant authority due to “public benefits”.

Another form of regulation is that of routing licensing system which imposed a limitation that every single route was generally operated by only a single operator, except that the existing operator couldn’t afford to offer sufficient services to satisfy passengers’ need. An operator would be awarded the public passenger transportation franchise for a period of 30 years, after a routing licence was issued by the authority.

A third form of regulation is that of price, that is, the authority specified periodically a detailed fare scale to be followed by operators.

The fourth is equipments and level of service controls, in which the physical supply of a service was controlled. This could take the form of directly limiting the size or number of vehicles operated, or more often specifying the route and timetable to be operated.

The primary aim of the new legislation, which came into effect in 1996, was to minimize government involvement by reducing the level of regulation.

This 1996 new legislation removed some regulations which had applied to highway bus services, involving intercity bus services and local bus services. The most important feature regarding the operation of a newly defined highway bus services was the increasing freedom of entry into the industry, and into the partially-deregulated sectors in particular. At the same time, the granted public passenger transportation franchise was shorten for a period of five years. However, this was not so in the case of urban bus services. Price control has also been removed from specifying a fare range to only limiting the maximum fare charged.

A significant range of quality control covering aspects such as the design, safety and fitness of vehicles, and licensing of drivers, however, has been retained and strengthened, especially with regard to adequacy of maintenance following partial deregulation.

2.2 Changes to the structure of the bus service industry

The 1996 new legislation of partial deregulation made two specific changes in the structure of the bus service industry:

1. The abolition of the limitation that every single route was operated by a single operator allowed new private operators to enter the market.
2. The break-up of the Taiwan Motor Transport Company (TMTC). This company was to be privatized by 2001.

Changes in number of operators, number of vehicles, vehicle-kilometer and passenger-kilometer by type of operators, i.e. urban bus services and highway bus services, between 1994 and 2002 are shown in Table 2.1. The number of urban bus operators remained constant due to the regulation policy. Regardless both the number of vehicles and vehicle-km increased, ridership fluctuated over the period. This may imply that the use made of resources in the attainment of outputs was neither efficient nor effective.

Table 2.1 Changes in Number of Operators and Vehicles, Vehicle-kilometer and Passenger-kilometer by Type of Operator in Taiwan

	Urban Bus Services				Highway Bus Services			
	Number of Operators	Number of Vehicles (Vehicles)	Vehicle-km (Thousand Veh-km)	Passengers (Million passengers)	Number of Operators	Number of Vehicles (vehicles)	Vehicle-km (Thousand Veh-km)	Passenger-km (Million Pass-km)
1994	30	4,361	226,731	823	35	7,359	638,116	11,925
1995	30	4,390	225,883	760	34	7,155	618,051	10,541
1996	29	4,526	236,746	764	35	6,823	619,595	9,772
1997	29	4,789	243,887	795	38	6,265	570,684	8,611
1998	29	4,660	257,545	808	42	6,343	579,278	8,333
1999	29	5,089	270,328	830	49	6,473	593,259	7,925
2000	29	4,664	274,122	791	52	6,548	654,679	8,584
2001	29	4,637	283,461	804	51	6,259	677,902	8,948
2002	29	4,850	301,322	775	50	6,701	759,708	9,655

Source: Statistical yearbook of Ministry of Transportation and Communications (MOTC) for 2003.

The number of companies operating highway bus services show a small increase at deregulation, followed by a peak, then sustained. Except in 2001, the number of vehicles had adversely increased followed deregulation, despite the decreasing trends of the number of vehicles were already in place before deregulation. Highway bus vehicle kilometers increased by 33% over the period 1997 to 2002, passenger kilometers also increased by 12% during the same period.

2.3 Market shares by ownership types of highway bus operator

The proportion of vehicle kilometer operated by different categories of enterprise, i.e., privately own enterprise (POE) and stately own enterprise (SOE), between 1994 and 2001 is shown in Table 2.2 for Taiwan as a whole.

Table 2.2 Market Shares by Owership types of Highway Bus Operator in Taiwan

	Stately own enterprise (ex TMTC)		Privately own enterprises		Total	
	Vehicle-km (10^3 veh-km)	Passenger-km (10^6 pass-km)	Vehicle-km (10^3 veh-km)	Passenger-km (10^6 pass-km)	Vehicle-km (10^3 veh-km)	Passenger-km (10^6 pass-km)
1994	284,843 (0.45)	5,046 (0.42)	353,273 (0.55)	6,879 (0.58)	638,116	11,925
1995	268,013 (0.43)	4,513 (0.43)	350,038 (0.57)	6,028 (0.57)	618,051	10,541
1996	245,021 (0.40)	4,068 (0.42)	374,574 (0.60)	5,704 (0.58)	619,595	9,772
1997	169,549 (0.30)	3,197 (0.37)	401,135 (0.70)	5,414 (0.63)	570,684	8,611
1998	149,888 (0.26)	2,741 (0.33)	429,390 (0.74)	5,592 (0.67)	579,278	8,333
1999	135,270 (0.23)	2,355 (0.30)	457,989 (0.77)	5,570 (0.70)	593,259	7,925
2000	133,185 (0.20)	2,147 (0.25)	521,494 (0.80)	6,437 (0.75)	654,679	8,584
2001	64,169 (0.09)	1,066 (0.12)	613,733 (0.91)	7,882 (0.88)	677,902	8,948

Source: (1) Statistical yearbook of Ministry of Transportation and Communications (MOTC) for 2001.

(2) Statistical yearbook of Highway Bureau, MOTC for 2001.

Note: (1) TMTC was privatized in July 2001.

(2) The figure in parenthesis represents the percentage of the corresponding vehicle kilometers or passenger kilometers.

The structure of the industry has undergone fundamental change since deregulation, perhaps the most striking point from Table 2.2 is that the significant expansion of the POEs. Specifically, the proportion of kilometer operated by this sector has risen nearly one-third compared with the immediate post-deregulation period (between 1997 to 2000). The SOE, on the contrary, has gone to opposite extremes and lost lots of its share. The POEs have experienced a 46% increase in passenger kilometers since deregulation, but the SOE, by contrast, has suffered a 33% decrease over the same period.

2.4 Privatization of the Taiwan Motor Transport Company

The TMTC was set up in 1980, since then, the Taiwanese intercity bus services have been provided by the nationwide TMTC in monopoly. However, a long-term trend decline about 10% per annum in intercity passenger journeys from 1980s has been seen, mainly due to the increasing use of private cars and illegal bus services following the opening of the first national highway in 1979. Subsequently, during 1990s, both endogeneous and exogeneous factors led to a major structural change in the Taiwanese intercity bus industry. Several influences occurred within TMTC itself. First, public management was exceeding inefficient. Under the operations of TMTC's 50 subsidiaries (stations) in 1990, there were 105 national highway lines and 102 provincial highway lines with a total of 3,070 vehicles. The number of TMTC employees was 13,000 by 1990. The number of employees per vehicle was more than four, approximately double the average of privately owned local bus operators. Secondly, the TMTC's quality of service severely deteriorated. Its fleet, where more than half the number of vehicles were more than 10 years old, was the least-maintained part of the system. Complaints about its poor services began to increase. Part of its operational inefficiency should attribute to both TMTC's management and its employees, and the rest of it was directly caused by governmental and politicians' intervention in controlling the transportation industry. For example, without governmental approval (usually time consuming), TMTC could not determine its budget, fare, staff salaries and authority for new services (such as renew rolling stock). In addition, it was always required to serve cost-inefficient social goals and operate unprofitable lines. These aforementioned factors, not only combined to either increase the cost or reduce the productive efficiency but also resulted in a deficit of a million U.S. dollars accumulated in 1999. TMTC was unable to pay the debt service of its bonds and became a grant and subsidy soaking company, which allowed it to be relatively more irresponsible and inefficient.

Besides these pressures mentioned above for TMTC's privatization, there were three major exogeneous factors from the government's decision-making. First, intercity bus service provision within Taiwan has undergone fundamental change over the last decade, moving from a publicly owned and heavily regulated industry to a privately owned and partially deregulated market. Specifically, the intercity bus was still subject to quality control and price cap regulation because of its fare; however, restriction of entry was removed to a great extent. The first POE was allowed to enter the national highway bus market running on 26 lines in 1990 and was able to provide alternative intercity service other than TMTC. Following the partial deregulation of bus industry in 1995, many POEs successively set up entirely new services but almost parallel to the national highway lines, altogether 22 POEs with 32 lines, with those of TMTC's by 1999. TMTC continued to operate, lacking innovation in competition with these increasing new entrants, eroding its revenues, and making achievement out of sound financial condition impossible.

Secondly, in respond to a request from the government, TMTC began to implement an organization reform, mainly to both downsize its personnel and pass (to POEs) or close its less-attractive lines to reduce its increasing cost from 1995. However, the deficit was still increasing until 1998. The then government decided to privatize TMTC by 2001. Thirdly, in 2000, there was political enthusiasm for proceeding to reform public organizations under the newly-elected DPP (Democratic Progressive Party) government. Excessive cost due to inefficient management and thus suffering the problems of long-period loss making was another driving force for reexamining the performance of the TMTC. And lastly, the TMTC's financial crisis on the verge of bankrupt at the end of 1999 served as a further impetus for accelerating the privatization of TMTC.

All these factors led to the TMTC's privatization. The privatization has produced major structural changes in the intercity bus industry. Some of these important changes, characterizing its privatization, can be summarized into two points: First, the TMTC was fully privatized by transferring hundreds of vehicles, 53 of 62 national highway lines and 43 of 83 provincial lines, together with all the 15 stations and depots to some 1,100 employees (out of 3,100 employees), the resultant private enterprise became organized as Guo Guang Motor Transport Company (KKTC). The rest of national and provincial lines as well as remaining old vehicles were passed to existing local bus companies by means of tendering. Second, KKTC was awarded a public passenger transportation franchise for a period of five years. Today, the KKTC is a good example of a POE operating in a similarly partially deregulated transportation market but almost entirely free from the government's restriction as a SOE.

Thirdly, subsequent to TMTC's privatization, other three nationalized enterprises, including Taipei Municipal Bus Company, have followed this successful case to impletement their programme of privatization.

CHAPTER 3

Literature Review

It's only quite recently that frontier studies have been developed as an appropriate methodologies to the transport sector, and the majority of studies have been published during the 1990s. A comprehensive survey of frontier methodologies and empirical results for public transit has been presented by De Borger et al. (2002). The existing frontier studies measuring urban transit performance have also been systematically summarized and critically assessed by them. In this chapter, frontier studies of transit systems are first reviewed, then the relevant researches concerning transit efficiency measurement, including frontier studies in Taiwan, input and output measures in transit, related studies of transit performance, as well as related studies of transit privatization are briefly reviewed.

3.1 Frontier studies of transit systems

Methods of measuring efficiency can be broadly classified into non-parametric and parametric. Non-parametric methods include indexes of partial and total factor productivity (TFP), and data envelopment analysis. The latter is essentially a linear programming based method. Parametric methods involve the estimation of neoclassical and stochastic cost and/or production functions (Gillen and Lall, 1997).

An overview of non-parametric and parametric frontier studies concerning bus transit systems is presented below.

3.1.1 Non-parametric approach

Regarding applications to transit efficiency studies, non-parametric approach have been used in the following cases.

Chu et al. (1992) used DEA to develop a single measure for the efficiency and a single measure for the effectiveness of a transit agency relative to other agencies within the same peer group. By using a single measure for each of these criteria, the paper provided a more robust indicator or transit performance than the widely used multiple ratio analysis performed in the Irvine Performance Evaluation Method (IPEM). Their analysis reinforced the notion that, for a public agency, measures of efficiency should be kept distinct from measures of effectiveness.

Obeng (1994) studied subsidy-induced technical inefficiencies in public transit systems using DEA in the United States. He found that subsidies improved technical efficiency in approximately 75% of the transit system studied. These efficiency improvement resulted in total cost savings of $13.66 million or $0.187 million per transit system. He argued that the type of subsidy given to the transit systems may determine its impact on technical efficiency. He notes that an output-based subsidy and capital subsidy are important in determining transit efficiency.

Nolan (1996) used the DEA approach with a second stage regression analysis to study technical efficiency determinants in the United States transit sector. Among other things, he concluded that operating subsidies created significant and negative impacts on efficiency. Agencies that received larger subsidies from state (but not federal) government had less incentive to produce efficient levels of output.

Kerstens (1996) evaluated the performance of a sample of French urban transit companies using a broad selection of nonparametric reference technologies for two specifications of the production process. In particular, the variable returns to scale DEA models with either strong or weak disposability in both inputs and outputs, and the Free Disposal Hull (FDH) are applied. An extensive comparison of the resulting radial output efficiency measures yields the following major methodological conclusions. First, the location of the efficiency distributions differs substantially depending on the methodology and especially on the output specification considered. The latter differences vanish if the impact of outliers is eliminated. Second,, convexity has a stronger influence on the efficient-inefficient dichotomy than allowing for congestion by means of a weakly disposable DEA model. For policy purposes, these efficiency distributions are explained using a Tobit model. The findings corroborate results reported elsewhere: the harmful impact of subsidies, etc. Furthermore, the network structure seems to account for some differences in performance. Finally, a novelty in the urban transit context is the indirect monitoring effect of the French earmarked transportation tax.

Roy (1996) studied the productivity of the transport sector in Canada using the total factor productivity (TFP) index at the aggregate level. He found that total productivity of Canada's transport sector grew by 15 per cent over the 1981 to 1993 period (1.1% per annum). He also found that since the mid-eighties, productivity had been trending downwards in passenger carriers, while the gains of freight carriers had been accelerating since 1986. However, he excluded urban carriers such as transit systems, taxicab operations, and special services such as school bus operators from the analysis.

Lyons (1997) indicated that there are many ways to look at productivity in the transit industry. The most commonly used indicators of performance are partial measures of efficiency. Recent studies have focused on developing a single measure of overall transit performance based on TFP and/or DEA models. However, these studies use different theoretical concepts, measures of output and input, and data sets to measure productivity. The objectives of this dissertation are: to determine whether the use of different single measure performance indicators yields consistent results; to determine whether there are significant differences in performance as measured by total and/or partial indicators; to explore which set of partial measures can best be used to predict overall performance; and to examine the influence of operating environments on overall performance. The overall measures used are TFP and DEA. Cross-sectional panel data are used for 93 urban transit firms which had 50 more buses in 1986, 1988, and 1990. Analysis revealed that the overall measures of productivity yield consistent results when the output variable remains fixed. However, the designation of firms as “best” or “worst” performers is substantially influended by the choice of the output variable. There are significant differences in performance as measured by overall and/or partial measures, but commonly-used partial measures are good predictors of overall productivity. While operating environment does matter, characteristics influenced by transit managers and policy-makers explain much of the variation in overall performance.

Viton (1997) studied the efficiency of U. S. multi-mode bus transit systems by asking whether they could expand their service (outputs) without requiring additional resources (inputs); or whether they could reduce input utilization without having to reduce service. He used the DEA technique in the study. The findings indicated that the degree of inefficiency present is small: decision-making units (DMUs) could reduce input usage by an average of only four percent without curtailing services, or could increase service by an average of only six percent without requiring additional inputs. Just under 80% of the sample was technically efficient, and about 20% of the industry was to some degree inefficient. The incidence of inefficiency was not strongly correlated with system input or output characteristics.

Viton (1998) examined the claim that US bus transit productivity had declined in recent years. It did so with reference to a piecewise-linear best-practice (DEA) production frontier, computed for multi-modal bus transit between 1988 and 1992. Efficiency was measured both by a Russell (Static) and Malmquist (dynamic) measure of productivity change. The principal finding was that, overall, bus transit efficiency had improved slightly over the period.

Button and Costa (1999) indicated that the regulatory framework under which the European transport network operates has changed significantly over the last 15 years. At the macro level the creation of the Single European Market has removed many of the institutional impediments to international transportation within European Union. At the meso level national governments have liberalized inter-city authorities have acted to introduce greater market incentives in the provision of local public transport. This paper is primarily concerned with the effects on economic efficiency of measures which have resulted in more liberalized markets at the local levels. In particular, it focuses on expanding the relatively scant empirical literature in this field by quantifying the impacts of major regulatory changes in two major European cities. The input minimization version of DEA programming is used for the empirical analysis.

Nakanishi and Norsworthy (2000) stated that in the past few decades, the market share of bus passengers has declined, while many transit services have expanded. Furthermore, wage rates and other costs of labor such as benefits have been increasing, and regulations relating to the environment and Americans with disabilities have been enacted. This has fueled a systemic decline in productivity of agencies providing bus service. With increasing pressures on public agencies to be accountable to taxpayers and constrain resources, the efficiency of transit agencies must be addressed. The measurement of productivity is the initial step that must be taken toward improved performance. The authors use DEA, a linear programming technique, to estimate the relative efficiency of transit agencies providing motor bus service. DEA is a nonparametric approach, used to and generate a best practice frontier and rank DMUs. The agencies that are efficient comprise the frontier and those that are not are ranked according to how far they are from their best practice counterpart on the frontier. The results generated from the DEA model are part of the first phase of the transit productivity study the authors have undertaken. Subsequent phases will examine other measurement techniques such as TFP and econometric estimation of scale and scope economies.

Odeck and Alkadi (2001) evaluated, from a productive efficiency point of view, the performance of Norwegian bus companies subsidized by the government. The framework was that of a deterministic non-parametric DEA approach to efficiency measurement. In this context several important issues were addressed: efficiency rankings, distribution and scale properties in the bus industry, potentials for efficiency improvements in the sector, the impact of ownership, area of operation and scope, and ways of improving efficiency in the sector. The findings showed that the average bus company exhibited increasing return to scale in production of its services. The extent of such returns however vary, with size and was more prevalent among smaller companies. The average bus company was found to have a considerable input saving potential of about 28 percent Neither economies of scope nor company ownership were found to have an influence on company performance. It was suggested that geographical factors needed a closer attention in future research.

Pina and Torres (2001) indicated that in recent years in the European Union (EU), they have witnessed an externalization process of the provision of local government services, in order to separate the political responsibility and the direct delivery of the service. The reasons that justify this process are focused on the belief that the private sector is more efficiency in carrying out economic activities, the pressure to reduce the public deficit and the public debt, the search for management systems that bypass public administration procedures, and the increase of control on local governments in auditing and accountability issues. The objective of this paper is to compare the efficiency of public and private sectors in the provision of urban transportation services. This paper shows the results of an empirical study commissioned by the Regional Audit Office of Catalonia (Spain), in order to evaluate the efficiency with which urban transportation services are delivered in the most important cities of this region. This efficiency study has been carried out using the DEA model, multiple linear regression and logit and cluster analysis. The results allow them to conclude that, in the cities studied, exogenous factors are not relevant and the private management of urban transport service is not more efficient than public management.

Cowie (2002) indicated that the British Bus industry had undergone considerable transformation since privatization. Five major operators had emerged to dominate the market, a position almost exclusively attained through acquisition. He reviewed the economies of scale argument commonly cited for this change and gave an overview of the acquisition process. He questioned whether this argument gave a complete explanation for this industry development. For 58 individual companies, the level of technical efficiency attributable to firms operating at or near the optimum level of output was examined over 5 years to determine if mergers in practice had resulted in scale economies. Technical efficiency was estimated using data envelopment analysis, under assumptions of constant and variable returns to scale. Efficiency scores were then regressed on a time trend and a merger dummy to test whether acquired firms' efficiency had significantly improved above the average. It was found that over the period, efficiency had improved. This improvement, however, could not be wholly attributed to the achievement of economies of scale. More specifically, there had been an improvement in the internal efficiency of acquired firms and some scale economies within group companies, the latter of which might have resulted from the eradication of competition.

Nolan et al. (2002) examined the extent to which subsidized urban transit agencies complied with the ISTEA (Intermodal Surface Transportation Efficiency Act) requirements of both technical and social efficiency. To do this, they proposed a method of measuring both technical and social efficiency using DEA. They found that in general, urban transit agencies did not pursue the social objectives (e.g. reduction of air pollution, increased safety and job creation) specified by ISTEA which was passed in the US in 1991.

Karlaftis (2003) developed an efficient frontier production function in a three-stage approach to investigate transit production and performance. First, efficiency rankings and efficient subsets of transit systems are obtained through DEA, a non-parametric linear programming based methodology. Second, based on the results of the DEA analysis, globally efficient frontier production functions, in the context of transit operations in the United States, are built. Third, convex programming is used to extract the aggregate production function for the transit systems examined. The results indicated that when jointly considered, there was an improvement on both the theoretical and empirical aspects of examining efficiency and production in transit systems. Further, the results indicated that efficiency and returns to scale findings differed substantially depending on the evaluation methodology used.

Odeck (2003) examined the efficiency of Norwegian bus industry to gain insight about factors affecting it. Non-parametric DEA was used to examine and decompose efficiency differences into input saving, output increasing and scale efficiency scores. Further. Mann-Whitney rank test was employed to test for efficiency differences with respect to ownership, region of operation and size. The results suggested that there was in general a potential for input saving in the whole sector of about 21 percent. No significant differences were found between urban and rural operators with respect to efficiency scores, neither were there any performance differences with respect to ownership. This latter result deviated were from previous international studies and could be explained by the lack of competition in the Norwegian bus industry. The crucial issue was thus less a question of differences in ownership or region of operation, but more a matter of sub-optimal input allocation, which varied according to size of operations .The analysis demonstrated that DEA was an appealing procedure for assessing efficiency in the bus industry.

Karlaftis (2004) indicated that the need to measure transit system performance along with its various dimensions has led to the development of a large number of quantitative performance indicators. However, depending upon the specific indicator examined, different conclusions can oftentimes be reached regarding performance. Further, although performance and scale economies are closely related issues, they have been generally examined separately in the transit literature. The research reported in this paper uses DEA and globally efficient frontier production functions to investigate two important issues in transit operations: first, the relationship between the two basic dimensions of performance, namely efficiency and effectiveness; second, the relationship between performance and scale economies. Using data from 256 US transit systems over a five-year period the results indicate that efficiency and effectiveness are positively related. Further, they imply that the magnitude of scale economies depends on the output specification.

3.1.2 Parametric approach

In regard to applications to transit efficiency studies, parametric approach have been employed in the following cases:

Viton (1986) estimated a flexible frontier specification for the production of urban bus transit services in the United States. The results confirmed previous findings of relatively unimportant scale economies. The paper found that locally decreasing returns in both short and long run prevail; more importantly, that substantial technical inefficiency prevails. There was no evidence that allocative efficiency varied systematically with firm size, nor did it appear that technical inefficiency varied systematically over firms.

Obeng et al. (1992) analyzed the TFP of single-mode bus transit systems in the United States. The analysees show that except from 1985 to 1986, TFP increased every year from 1983 to 1988. The rate of increase in TFP is 1.1% per year and its sources are capital, output and the productivity of all inputs .The contributions of labour and fuel moderated the rate of growth of total factor productivity. Further, the trend in the rate of change of TFP was similar to the rates of change of output, labour productivity and capital productivity and different from the trend in fuel productivity. They used the translog cost function in the analysis.

Thiry and Tulkens (1992) first identified and evaluated efficient versus inefficient observations numerically by the nonparametric FDH method. Next parametric production frontiers were obtained by means of estimating translog production functions through ordinary least square (OLS) applied to the subset of efficient observations only. Technical progress was included at both stages. Monthly data from three urban transit firms in Belgium, to which this two-stage technique was applied, showed widely varying degrees of efficiency over time and across firms, and much less technical progress than standard (i.e., non-frontier) econometric estimates suggested.

Fazioli et al. (1993) presented evidence for scale inefficiency and overall cost inefficiency for 40 regional bus companies in a region of North-Italy. A translog cost function for a five-year panel is estimated and measures of economies of scale and density are derived. The estimation results allow for a discussion of inefficiency in terms of sub-optimal scale and density. Overall cost inefficiency is estimated by means of a frontier cost function. The findings are discussed in the Italian political and regulatory context.

Bhattacharyya et al. (1995) estimated the determinants of cost inefficiency of several publicly operated passenger-bus transportation companies in India in terms of their ownership structure as well another firm-specific characteristics. A panel data on publicly operated passenger-bus transportation companies was used to estimate a translog cost system with inefficiency. Inefficiency was specified in such a way that both its mean and variance are firm- and time-specific. For the estimation of production technology and cost inefficiency they have used a multi-step estimation procedure instead of the single-step maximum likelihood (ML) method. In the first step they estimated the translog cost system with heteroskedastic cost function without using any distributional assumptions on the error terms. The second stage used the ML method to estimate the parameters associated with inefficiency, conditional on the parameter estimates obtained from the first stage. Finally, the residual of the cost function was decomposed to obtain firm- and time-specific measures of cost inefficiency, with ownership type and other firm-specific characteristics as explanatory variables.

Jorgensen et al. (1997) estimated a stochastic cost frontier function based on data from 170 of the 175 Norweigian subsidized bus companies under two alternative presumptions regarding the distribution of the inefficiency among the bus operators. When the inefficiency was assumed to be half-normally distributed, the average inefficiency in the industry is estimated to be 13.7 per cent. This calculated value was nearly halved (7.2 per cent) when the exponential distribution was applied, while the ranking of the companies according to inefficiency was unchanged. By regressing the estimated inefficiency values for each company on some exogenous variables describing its ownership structure and the subsidy policy which it faced, it was seen that inefficiency of the companies which negotiated with the public authorities over the subsidy amounts was slightly higher than the inefficiency of the companies which faced a subsidy policy based on cost norms. Their analysis gave, however, no significant difference in the efficiency between privately owned bus companies and publicly owned bus operators, and showed only minor economies of scale.

Sakano et al (1997) studied the US urban transit systems which received operating and capital subsidies from various levels of government. Each firm minimized its cost net of subsidies subject to its production function. The first order conditions from this minimization gave a set of equations that were estimated using a stochastic frontier approach. From the results, technical and allocative inefficiencies were calculated. The allocative inefficiencies were further decomposed among two sources, subsidies and factors internal to the firm. The analysis revealed large allocative inefficiencies between labor, fuel, and capital. Furthermore. They found that subsidies lead to excess use of labor relative to capital and excess use of fuel relative to capital and labor. Also, most allocative inefficiencies in firms were due to internal factors and not subsidies, and the sizes of the inefficiencies varied substantially among transit firms.

Matas and Raymond (1998) stated that the aim of their study is twofold. First, to provide new information concerning the technical characteristics of urban bus companies on the basis of a sample of medium and large-size cities in Spain. Second, to analyze the degree of efficiency of those companies and to quantify the reasons for this efficiency. The results should be useful in evaluating possible changes in public policies relating to urban transport, specifically changes in the way the market is organized and in pricing.

The analysis is carried out by estimating a cost function. The sample is made up of a panel data set consisting of observations of nine Spanish companies that operated during the period 1983-1995. The specified functional form is translogarithmic. The output unit of measure adopted is bus-kms run. The cost function includes the network length for each company, thus permitting evidence concerning economies of density and economies of scale.

The use of panel data allows them to estimate the cost function, taking into account that each company is affected by the specific characteristics of each individual city, the different features of the network in question and by different levels of efficiency. The economies of scale have been calculated, taking into account that the features of the network and of the city–represented by their specific individual effect – will vary with the company's level of output. Finally, an analysis is made of the relative productive efficiency of the companies, as well as of the variables likely to influence that efficiency.

Obeng and Sakano (2002) decomposed the rate of growth of TFP in public transit systems among input demand effects, an indirect output effect, an indirect technical change, pure scale effects and pure technical change. An application of the decomposition to selected transit systems was provided. The application shows that the effects of the changes in input price inefficiencies on TFP are sizeable, and that the total subsidy effects on TFP were larger than the total effects from utility maximization behavior. Furthermore, the traditional sources of TFP (i.e. pure scale and technical change) reduced TFP and the Divisia index overestimates TFP in public transit systems.

More recently, Dalen and Gomez-Lobo (2003) addressed a cost frontier model which was estimated for an eleven-year panel of Norwegian bus companies (1136 company-year observations) using the methodology proposed by Battese and Coelli (1995). The main objective of the paper was to investigate to what extent different type of regulatory contracts affect company performance. The panel model proposed by Battese and Coelli (1995) allow for year/company specific efficiency measures to be estimated. Thus, unobservable network or other time invariant characteristic of the operating environment can be controlled for by analyzing the dynamics of measured productivity across time for firms regulated under different types of contracts, rather than relying solely on variations across companies during one time period. Therefore, the paper offers methodological and data advantages over previous work on this subject. The main and robust result of the paper is that the adoption of a more high-powered scheme based on a yardstick type of regulation significantly reduces operating costs. The results contained in this paper thus confirms theoretical predictions regarding the incentive properties of high powered incentive schemes and in particular the dynamic benefits of yardstick competition.

3.1.3 Frontier studies in Taiwan

The DEA studies concerning Taiwanese bus transit system are reviewed as follows.

Chang and Kao (1992) employed the data envelopment analysis method to evaluate the efficiency of the five bus firms in Taipei city. When vehicle kilometers (revenue or the measure combining vehicle kilometers, revenue and the number of traffic trips on routes) was used as the output measure, it concluded that the publicly owned Taipei Municipal Bus had increased (not increased) its technical efficiency after the government liberalized the urban bus market. This article also found that in both the one output (vehicle kilometers) and three outputs cases, Taipei Municipal Bus had, on an average, lower efficiency scores than the private firms, and that while each firm usually employed a linear production technology for several, consecutive years the private firm were more flexible in adopting different technologies.

Cheng and Shiau (1994) extended the traditional one-stage performance approach, which only considered the relationship between input and output, to the two-stage performance approach that combines the concepts of efficiency and effectiveness to evaluate the relative aggregate performance among highway bus operators (HBOs). The DEA model modified by CCR (Charnes, Cooper and Rhodes) was applied to develop a two-stage performance model that includes:

1. a relative efficiency evaluation model that explored the relationship between input and output, and
2. a relative effectiveness evaluation model that explained the relationship between output and consumption.

Operation data of 32 HBOs were collected (1987 to 1991) and were used to perform the relative performance evaluations at cross sections of time, and over the series of time. These results of production structure showed that the production technologies were quite different among HBOs, and generally inflexible in the short term. Regarding the efficiency of resource use, most of the HBOs went from bad to worse in the recent years. In effectiveness of output utilization, the output of the HBOs which served in the central, southern and eastern Taiwan were utilized less effectively than that of the HBOs in the northern Taiwan. In addition, this study also found that the HBOs with better relative performance in the one-stage model presented the worse results on either relative efficiency or relative effectiveness of the two-stage model. This result indicated the two-stage performance approach could more precisely evaluate and distinguish between the efficiency of resource use and the effectiveness of output utilization. This study could help an HBOs to identify future directions for improving operation performance.

Change and Sun (2001) presented a two-stage model for measuring the performance of Taipei urban bus companies. The bus transit performance is measured in terms of overall performance, operation efficiency, operation effectiveness, service effectiveness, and cost efficiency. This paper concludes that:

1. Shoutu and Hsinhsin (1998). Tayo (1997-1999), Sanchung (1997, 1999), Sintien, Fuho and Hsinbo (1999) reached overall efficiency;
2. Hsinho (1997-1999) reached operation efficiency;
3. HsinHsin (1997-1999), Fuho, Hsinho (1999) reached operation effectiveness;

4. Hsiho (1999), Tamsui (1997), Fuho (1997,1999) and Tayo (1997,1998) were rated service efficiency;
5. Tayo (1998). Fuho and Hsinho (1999) reached cost efficiency;
6. High efficiency means high service effectiveness while high efficiency doesn't mean high operation effectiveness; and
7. High overall performance means high cost efficiency.

Chang (2003) indicated that TMTC was the largest public intercity bus company in Taiwan. With a cumulative debt over 40 billions NT dollars, TMTC was one of largest financial burdens of the government and then forced to privatize in July 2001. The objective of this study is to examine the impacts of privatization. The operating data of TMTC before and after privatization. From the operator perspective, before and after analysis was applied first to compare the major performance measures. The results show that all the performance measures are significantly improved. From the user perspective, a questionnaire was designed to survey the perceived changes by the users. The results show that most users agree that the services have been significantly improved after privatization. In order to closely examine the impacts of privatization on operating performance, the DEA was also applied to compare the relative efficiency for the 14 major service lines. The Tobit regression analysis was followed to analyze the service variables and characteristics that can significant influence operating efficiency. The results indicate that service distance over 150 kilometers, freeway lines, the number of competitors, and providing demand responsive service can significantly increase service efficiency. Overall, privatization provides positive impacts on intercity bus services.

Cho and Fan (2003) empirically examines the property right theory in economics comparing the performance of TMTC before and after privatization. The criteria of both the Malmquist TFP Index and its decomposing techniques are used to estimate this performance change in the framework of the DEA. This study has found that TMTC's privatization has had a positive impact on the productivity enhancement and hence confirmed the property right theory, but no evidence was found that the technical efficiency improved because of privatization. Therefore, this study presents some management problems with regard to inefficiencies existing within the TMTC's privatization. Future works are also suggested.

Cho and Fan (2004) propose three categories of productivity measures to investigate the changes of production productivity, service productivity as well as consumption productivity following TMTC's privatization. The results indicate that privatization had a striking impact, in terms of TFP, on various productivity growths. The decomposing results demonstrate that the technical change was the most important factor for the new owner's (KKTC's) productivity progress while efficiency of effectiveness change had little contribution to this growth. However, further decomposing results suggest that the insignificant efficiency of effectiveness in the newly-privatized firm may be attributed to either incorrect selection of input combinations or inappropriate returns to scale or to both.

In summary, all the literature reviewed above, can be divided into three groups in terms of measure, that is,

1. technical efficiency,
2. Malmquist total factor productivity (TFP) index, and
3. efficiency and effectiveness (or cost efficiency).

These are listed in Table 3.1 below. In terms of research topics, the literature reviewed can be classified roughly into five categories:

1. Privatization (Cowie 2002; Cho and Fan 2003, 2004);
2. Regulation (Button and Costa 1999; Nolan et al. 2002; Dalen and Gomez-Lobo 2003);
3. Owership (Change and Kuo 1992; Jorgensen 1997; Pina and Torres 2001; Odeck 2003; Cho and Fan 2003, 2004);
4. Subsidy (Obeng 1994; Sakano and Obeng 1995; Nolan 1996, 2002; Sakano et. al. 1997; Jogensen 1997; Odeck and Alkadi 2001; Obeng and Sakano 2002);
5. Others (Chu et al. 1994; etc).

Table 3.1 Classification of the Reviewed Literature

	Technical efficiency	Malmquist TFP index	Efficiency and effectiveness
Non-parametric	Chang& Kao (1992), Oben (1994), Viton (1997,1998), Nolan (1996), Kerstens (1996), Costa et al. (1997), Button and Alkadi (2001), Costa (1999), Nakanishi and Norswrthy (2000), Pina and Torres (2001), Odeck& Alkadi (2001), Cowie (2002), Nolan et al. (2002), Karlaftis (2003), Odeck (2003), Chiang (2003)[1]	Viton (1998), Cho and Fan (2003,2004)[1]	Chu et al. (1992), Cheng&Shiau (1994), Roy (1996), Costa (1998), Change and Sun (2001)[1], Kalaftis (2004)
	Technical efficiency	**Malmquist TFP index**	**Cost efficiency[3]**
Parametric	Viton (1986), Thiry & Tulkens (1992), Sakano and Obeng (1995), Sakano et al. (1997)[2], Jorgensen et al. (1997), Mata&Raymond (1998)[2]	Obeng et al. (1992), Sakano et al. (1997), Obeng&Sakano (2002)	Fazioli et al. (1993), Battacharyya etal. (1995), Dalen&Gomez-Lobo (2003)

Note: [1] DEA study of Taiwanese bus transit industry

[2] with scale efficiency

[3] costs are used as the input variable

3.1.4 Input and output measures in transit

The discussion here partly follows the presentation found in Boame (2001) and partly in De Borger et al. (2002). The definition of outputs is problematic. The early literature focused on the distinction between pure supply indicators (vehicle-km or seat-km) and output measures that at least to some extent reflect the demand for transit services (e.g. passenger-km and number of passengers). Arguments for and against either specification are found in the literature.

For transit service, it is useful to consider two classes of output measures. One is a measure of trips taken. The ultimate purpose of transportation is to provide trips, and it is trips, or some aggregates of trips that are the output variables in travel-demand analysis. Small (1992) calls such output measures final outputs, and Berechman and Giuliano (1985) call them demand-oriented measures. In practice, final outputs are usually aggregated into total passenger trips, revenue passengers (the number of distinct fares paid), passenger-miles, total revenues (a valid output measure if the fare structure is held constant in the analysis), or total network miles.

As can be noted, however, that for the transit firm final outputs are not under its control. Hence the transit firm may be more interested in the cost of producing the potential for trips, as measured, for example, by vehicle-miles, vehicle-hours, network miles, or seat-miles of service. One may consider such measures to be intermediate outputs, because they are combined with user time to produce the final outputs. Berechman and Giuliano (1985) call them technical output measures because they are most directly related to the firm's exploitation of transportation technology.

The two output measures could be redefined in terms of the amount of service provided (vehicle-miles, vehicle hours, network miles, or seat-miles) or in terms of the amount of service used (passenger-miles, passenger-trips). Miller et al. (1984) note that introducing measures of system use diverts the discussion of transit output into the area of system effectiveness. The concept of effectiveness has evolved to address the question, " How well does the system serve its intended users?" By contrast, the efficiency question may be phrased, "How well does the system combine inputs to produce service?" Perelman and Thiry (1989) argue that if one is primarily concerned with the productivity and efficiency in production, one should use measurements of production and supply, not variables influenced by demand.

Technical efficiency of a production process is more accurately measured when demand-side influences on output measures are minimized. Gathon (1989) notes that the number of passengers carried is greatly influenced by demand and hence not suitable for evaluating the production and supply of services from public transit firms.

When the transit systems have low load factors, the available output measures (e.g. vehicle miles, seat miles) may not be appropriate in some situations. In such cases, high efficiency scores indicate efficient operations of the transit systems, and may not necessarily reflect efficient usage of the buses. A relatively low efficient transit system may have high load factors, while a high efficient system may have low load factors. High efficiency measured in available output may imply that the transit system is efficient even though it produces a lot of useless outputs (empty buses).

On the other hand, De Borger et al. (2002) found that probably the most striking feature is the wild variability in the use of inputs and outputs in urban transit technology specifications. Most studies use labour and capital as inputs (Viton 1992 has an application using labour as the only input), but not all of them include energy (e.g. Fazioli et al. 1993). Some applications include environmental variables to provide more detail on input quality. For instance, Levaggi (1994) included a load factor, population density and network length as inputs, Chu et al. (1992) considered revenue, population density and percentage of households without a car, Tone and Sawada (1990) included operating expenses, and Costa (1998) included the network route length of the metro operator. A similar wide variety of indicators is observed at the output side. Parametric studies mainly use supply-oriented indicators such as seat-km or vehicle-km, with the exceptions of Bhattacharyya et al. (1995) and Levaggi (1994) who both selected passenger-km as appropriate measure of output. In non-parametric parametric work, there is a broader choice of outputs, although the vehicle-km or seat-km specifications are still the most common. Levaggi (1994) also considered passenger-km, Tone and Sawada (1990) had four applications with outputs of different nature. While most studies include a single output ,Chang and Kao (1992), Costa (1998), Tone and Sawada (1990) and Wunsch (1994) included applications with multiple outputs.

Overall, this variability in the input and output measures simply suggests that there is no generally accepted set of relevant variables in the bus industry.

3.2 Related studies of transit performance

Several literature of transit performance relating to this dissertation are summarized as follows.

Talley and Anderson (1981) indicated that the first national conference for transit performance concluded that transit performance embraced two concepts: effectiveness and efficiency. They presented a theoretical foundation for selecting effectiveness and efficiency performance criteria and standards by transit firms. The paper demonstrates that a transit firm must first specify its effectiveness and standards (since they could vary from firm to firm), but does conclude that a transit firm can not be effective without being efficient; transit effectiveness and efficiency are necessary conditions for transit subsides to be effective; and public transit firms should be evaluated form the perspective of the firm rather than that of government.

Fielding (1987) presented a balanced assessment of transit performance by using service input, output and consumption figures to measure three important dimensions of transit operations: efficiency, effectiveness, and overall performance. Efficiency describes how well factors such as labor, equipment, facilities, and fuel are used to produce outputs as represented by vehicle hours or miles of service. Effectiveness measures the consumption of transit output as well as the impact of transit on societal goals, such as reducing traffic congestion. Overall indicators integrate efficiency and effectiveness measures, as when costs of service inputs are related to consumption. Cost per passenger and the ratio of revenue to the cost of producing service are overall measures. Cost efficiency, service effectiveness, and cost effectiveness are the terms used to describe the three dimensions of transit performance presented in Figure 3.1.

He also indicated that efficiency as used here is what economists would call "production efficiency," meaning the resources used to produce output. Effectiveness is "distribution efficiency," which means the utilization of output to accomplish goals.

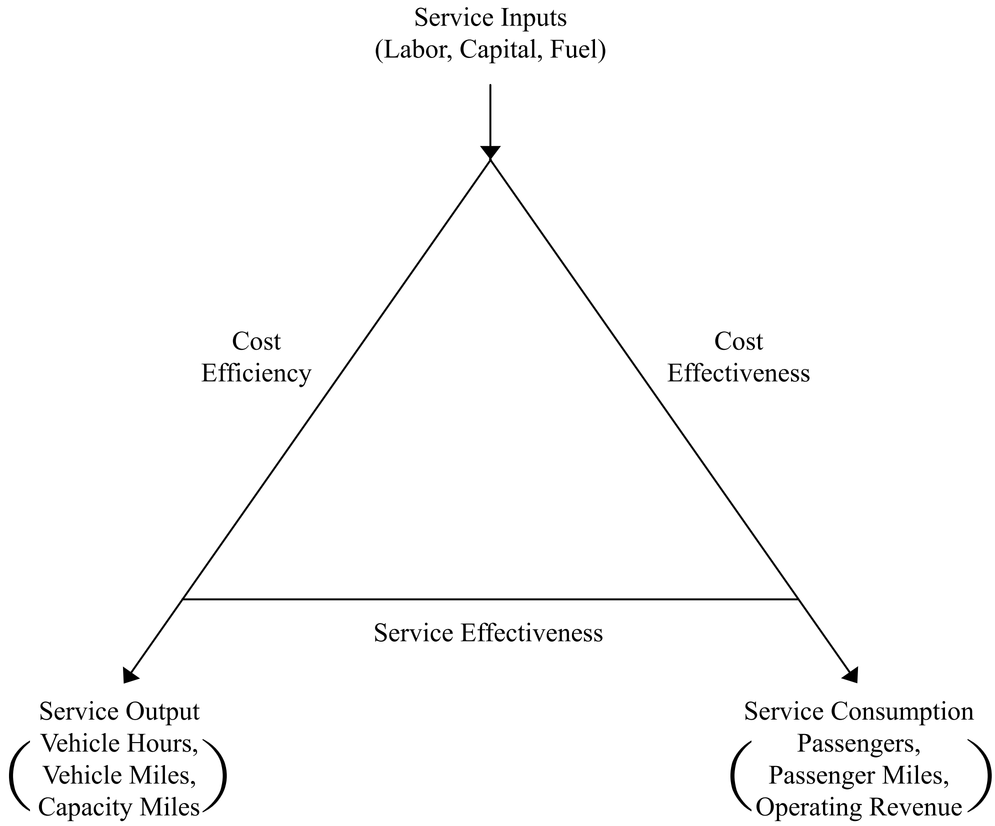

Figure 3.1 Framework for Transit Performance Concepts

Hensher and Daniels (1995) investigated the cost efficiency and cost effectiveness of private and public urban bus operators in Australia. An index of gross total factor productivity (GTFP) for each operator was developed and decomposed to identify the sources of variation across operators, such as the role of different institutional and regulatory constraints on relative performance. The results provided very strong evidence on the relative productivity of operators in the private and public sector operating under varying institutional and regulatory regimes.

Drawing upon the finding of Fielding (1987), Hooper and Hensher (1997) indicated that the cost efficiency of a transit agency represents the manner in which the physical inputs of labor, energy, maintenance materials, capital and overheads are used to produce the physical (intermediate) services such as frequency of service and vehicle-km. Cost efficiency is concerned with the supply-side relationships. Effectiveness has two essential components:

1. cost effectiveness－the relationship between inputs and consumed services (i.e., passenger－kilometer).
2. service effectiveness: the relationship between produced services (e.g., veh-km) consumed and (final) services (e.g., passenger-kilometer or passenger trips).

Cost effectiveness is concerned with demand-side relationships. The cost efficiency measure is of particular interest to the operator because it relates to the service levels to a great extent under their control, given passenger levels. Government regulators also are interested in how cost effective each operator is in serving passengers, this representing the prime purpose for being in business.

3.3 Related studies of transit privatization

With an increase in privatizations by governments, the academic literature concerning privatizations has also grown. Recent studies have focused on the effect of privatizations on the operating efficiency, capital spending, and profitability of a firm (Boardman and Vining, 1989; Megginson et al.,1994; Boubakri and Cosset, 1998; D'Souza and Meginson, 1999; Dewenter and Malatesta 2001.), the returns to investors from investing in privatized firms (Megginson et al. 2000 a, b; Dewenter and Malatesta, 1997), and other areas. Some of these results find that privatization increases profitability, efficiency, output, and capital spending. Some of the studies in the empirical privatization literature indicate that most privatizations are underpriced and provide positive returns to initial investors. Some in the literature also show that a firm's performance improves immediately following privatization and report that post –privatization ownership and management is important in achieving those results. There is additional evidence that privatization plans are politically driven and not necessarily revenue maximizing sales by the government (Harper, 2002).

Some earlier studies have focused on the financial performance of bus services. For example, White (1997) indicates that a dramatic reduction in real operating costs per bus-kilometer has been achieved in all areas within UK. This has resulted from a growth in labor productivity (especially through reducing the numbers of engineering and administrative staff), low real wages, lower fuel costs, reduced overhead, and lower fuel and maintenance costs of the new fleet. In addition, A number of the literature (Gomez-Ibarmez and Meyer 1990; Anderson et al. 1992; Mackie et al. 1995; Karlaftis and Sinha 1997, Alexandersson et al. 1998; Karlaftis and McCarthy 1999) using a variety of data and methodologies, found the results of privatization to be positive for the efficiency and productivity of bus transit systems.

A buy-out essentially means the purchase of a company from its current owners by the people who work in that organization. While all employees have the possibility to purchase shares in the company at the outset, but when they are not obliged to do so, the term employee buy-out (EBO) is used (Mulley and Wright, 1986).

According to Wright and Mulley (1989), case study interviews of twenty of the National Bus Company (NBC) buy-outs, undertaken in the first year after buy-out, found clear evidence that the break-up (of NBC) had given a great deal of freedom to introduce more appropriate organization structures, purchase appropriate fleet vehicles, reduce casts bases, and obtain fuel at lower cost than available through central purchasing. Wright et al. (1992) indicates that most of the cost savings of EBO appear to have come about through productivity improvements, particularly among non-platform staff and reduced pay and wages. Apart from the reduction in number of employees, there is evidence that working practices have changed following the breakdown of national bargaining resulting in increased flexibility. Furthermore, they identified the following effects in relation to government objectives. First, whilst the high level of buy-out activity in the privatization process appears to have recognized the importance of individual skills, the extent of wider employee ownership had been rather lower and the high level of subsequent merger activity had often made manager employee ownership a transitory phenomenon. Second, privatization seems to have brought lower unit costs and contributed to product innovation. Subsidy costs also appeared to have been reduced. But, third, entry deterrence has been a problem. Entrants appeared either to have been deterred by the costs and low profitability involved and predatory behaviour by incumbents. Statutory entry requirements have been substantially removed but the market may have natural monopoly features in local markets. This point implies further shake-out and alessening of competition as groups and alliances begin to emerge. The immediate period following deregulation may be interpreted as one of disequilibrium, where new firms entered, most were quickly driven out and those that survived did so by colluding with existing firms.

Boubakri and Cosset's finding reveals that the difference between the value changes in profitability and operating efficiency is significantly larger for the employee stock ownership plans (ESOP) firms than for the non-ESOP firm. This is consistent with the proposition that ESOPs favor employees' support for the privatization policy and performance improvements and is contrary to the Boycko et al. (1996) prediction that workers make poor stockholders/monitors.

On the other hand, numerous empirical studies have investigated comparative efficiency of different ownerships based on the "property right theory", which argues that private ownership would improve those firms' performance and overall efficiencies of the economy in similar circumstances. For example, some studies of public and private ownership suggest that POEs can achieve higher levels of operating efficiency than SOEs (Megginson and Nette, 2001), but other research confirms that the property right theory is not always true and its assertion depends upon the type of industry, its industrial structure, regulatory environment and nation. (Sueyoshi, 1998; Parker, 1999). The effect of property rights on efficiency and productivity, in their opinions, is ultimately an empirical question.

3.4 Limitations of previous research

After reviewing the current researches for transit efficiency analysis, it was found that these literature have some limitations.

First, it is especially unfortunate that only a handful of frontier studies have focused on the effects of privatization and regulatory changes (De Borger et al., 2002).

Second, most of the extant literature restrict their analysis to the use of technical efficiency (TE) rather than allocative efficiency (AE), due to

1. lack of price information, and
2. allocative efficiency assumes cost minimizing.

Third, a large strain of previous studies on measuring firm's efficiency are typically conducted without taking into account undesirable outputs which may not be freely or costlessly disposable.

Fourth, few DEA studies relating to transportation organizations which engage in various activities (services) deal with the allocation problem of shared inputs in a proper way.

Fifth, the perishability of the transportation service produced, and the fact that only a proportion of the service produced are actually consumed is often neglected in transit performance measures.

The potential impact of this omission is two-fold. First, by not including these important issues in an efficiency analysis, the transit system's primary activities are not being fully knowledged. The analysis is thus carried out by using a conventional model, this could lead to less demanding than by employing a refined model. Second, by including these issues in measure of transit efficiency, the accuracy and representation of the efficiency analysis for providing performance targets for inputs and outputs and for identifying benchmark operating practices can be improved.

CHAPTER 4

The Basic Data Envelopment Analysis (DEA) Model

The purpose of performance measurement is to compare behavior of organization over time, across space, or both. Furthermore, benchmarking comparisons can be made within a sector or across sectors, comparisons can be limited to the national level or may have an international character etc (De Borger et al., 2002). The focus in this performance evaluation of Taiwanese bus industry is on issue of efficiency and effectiveness. This chapter begins by distinguishing between (technical) efficiency and productivity－two related concepts that tend to be confused in daily usage, and which lie at the foundation of efficiency analysis. The discussion here closely follows the presentation found in Coelli et al. (1998) and De Borger et al. (2002).

4.1 Efficiency and productivity

The terms, efficiency and productivity, are often used interchangeably. But this is unfortunate because they are not precisely the same things. Though the concepts are related, in general, productivity can be thought of as being a broader concept than efficiency. Both concepts can be related to a production function which is the primitive (in the single output case) representing the transformation of inputs to output. From a conceptual viewpoint, efficiency measurement can be classified into the frontier and non-frontier approaches and from an implementation perspective, into parametric and non-parametric. These are discussed below. The productivity of a firm is defined as the ratio of the output(s) that it produces to the input(s) that it uses.

$$\text{productivity} = \text{outputs/inputs} \tag{4.1}$$

To illustrate the distinction between the terms, it is useful to consider a simple production process in which a single input (x) is used to produce a single output (y). The line OF' in Figure 4.1 represents a production frontier which may be used to define the relationship between the input and the output. The production frontier represents the maximum output attainable from each input level. Hence it reflects the current state of technology in the industry. Firms in that industry operate either on that frontier, if they are technically efficient, or beneath the frontier if they are not technically efficient. Point A represents an inefficient point whereas points B and C represent efficient points. A firm operating at point A is inefficient because technically it could increase output to the level associated with the point B without requiring more input.

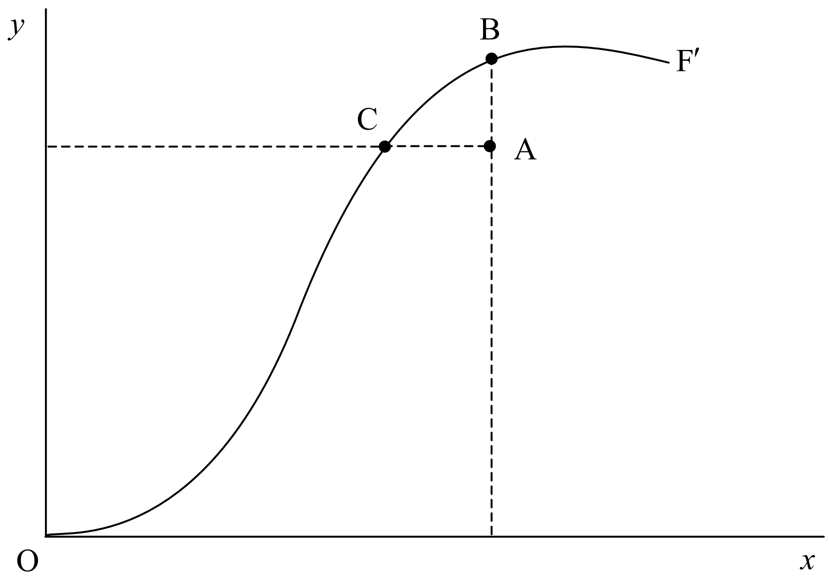

Figure 4.1 Production Frontiers and Technical Efficiency

Figure 4.1 also illustrates the concept of a feasible production set which is the set of all input-output combinations that are feasible. This set consists of all points between the production frontier, OF', and the x-axis (inclusive of these bounds). The points along the production frontier define the efficient subset of this feasible production set. The primary advantage of the set representation of a production technology is made clear when discussing multi-input/multi-output production and the use of distance functions below.

To illustrate further the distinction between technical efficiency and productivity, Figure 4.2 is utilized. In this figure, a ray through the origin is used to measure productivity at a particular data point. The slope of this ray is y/x and hence provides a measure of productivity. If the firm operating at point A were to move to the technically efficient point B, the slope of the ray would be greater, implying higher productivity at point B. However, by moving to the point C, the ray from the origin is at a tangent to the production frontier and hence defines the point of maximum possible productivity. This latter movement is an example of exploiting scale economies. The point C is the point of (technically) optimal scale. Operation at any other point on the production frontier results in lower productivity.

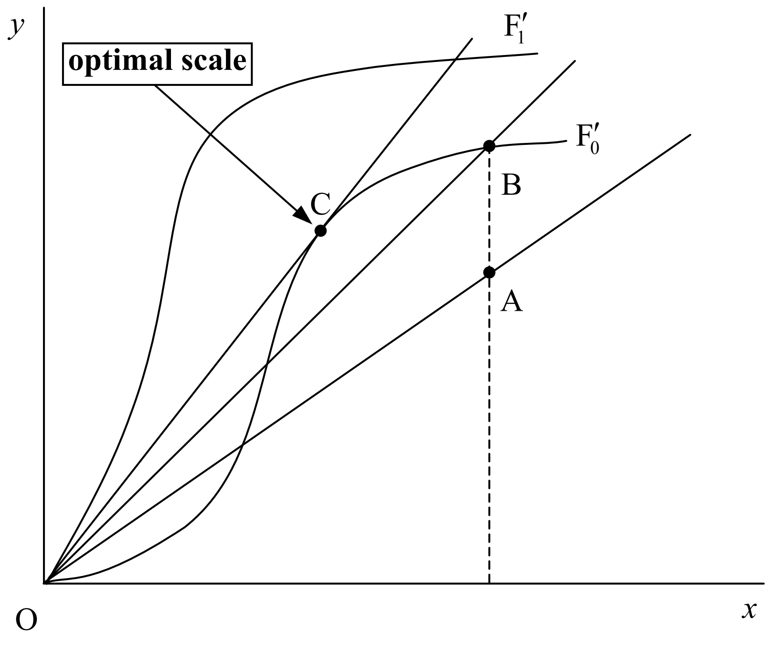

Figure 4.2 Productivity, Technical Efficiency, Technical change and Scale Economies

From this discussion, a conclusion can be drawn that a firm may be technically efficient, but may still be able to improve its productivity by exploiting scale economies. Given that changing the scale of operations of a firm can often be difficult to achieve quickly, technical efficiency and productivity can be given short-run and long-run interpretations.

In addition, when referring to productivity, it is total factor productivity (TFP) that is referred to. It is a productivity measure involving all factors of production. One of the popular measure is the Malmquist TFP index (See Caves et al. 1982 for detail) Other traditional measures of productivity, such as labour productivity in a factory, fuel productivity in power stations, and land productivity (yield) in farming, are what is known as partial measures of productivity. These partial productivity measures can provide a misleading indication of overall productivity when considered in isolation.

There is a variety of methods that can be derived for measuring performance based on the concepts of efficiency and effectiveness. In public agencies, efficiency should be considered separately from effectiveness. Efficiency is the relationship between inputs and outputs of what is referred to as "productive" or "technical" efficiency in the economic literature. Effectiveness, on the other hand, refers to the use of outputs to achieve objectives, or service consumption. However, in addition to efficiency and effectiveness, relationships also exist between the efficiency and effectiveness criteria. For example, the frequency of service (an efficiency criterion) affects riders' waiting time (an effectiveness criterion).

4.2 Frontier methodologies

To estimate production or cost frontiers, methods have been developed for analyzing time series, cross-section or panel data. Once frontiers have been estimated, productivity changes can directly be derived from shifts in the frontier over time. Technical inefficiency estimates are readily available as well, as is illustrated below.

Existing approaches to reconstruct production frontiers can be usefully distinguished along the lines below (A general survey is found in Lovell (1993). Färe et al. (1994) overviewed non-parametric methods, while Greene (1997) surveyed parametric frontiers).

1. Parametric versus non-parametric frontier specifications:

    (1) The parametric approach assumes that the boundary of the production possibility set can be represented by a particular functional form with constant parameters.

(2) The non-parametric approach imposes minimal regularity axioms on the production possibility set and directly constructs a piecewise technology on the sample.

2. Deterministic versus stochastic frontier specifications:

(1) Stochastic methods make explicit assumptions with respect to the stochastic nature of the data by allowing for measurement error.

(2) Deterministic methods take all observations as given and implicitly assume that these observations are exactly measured.

Combining these distinctions yields a four-way classification, as illustrated in Table 4.1. Since the literature on stochastic non-parametric frontiers is still burgeoning (recent proposals include resampling (bootstrap), chance constrained programming, etc.) and no consensus has yet emerged, this issue was not pursued here (Grosskopf 1996). The three other cells of Table 4.1 are introduced as follows.

Table 4.1 Taxonomy of Frontier Methodologies

	Measurement error	
Functional form	Deterministic	Stochastic
Parametric	Corrected OLS, etc.	frontiers with explicit assumptions (exponential, half-normal, etc.) for the TE distributions
Non-parametric	FDH,DEA-type models, etc.	resampling; chance constrained programming, etc.

Source: De Borger et al. (2002).

First, the early literature often used deterministic parametric frontier methods. However, given that they combine the most restrictive assumptions (deterministic and parametric) they are no longer very popular (Lovell 1993).

Second, the popular parametric frontier approach (sometimes referred to as the econometric frontier approach) is the stochastic frontier approach (SFA) which is based on the econometric regression theory. The SFA (see Aigner and Chu, 1968, Aigner et al. 1997, and Meeusen and van den Broeck, 1977, for details) specifies a functional form (e.g. translog or

Cobb-Douglas) for the cost, profit, or production relationship among inputs, outputs, and environmental factors, and allows for random error. Both the inefficiencies and the random errors are assumed to be orthogonal to the input, output, or environmental variables specified in the estimating equation.

Third, the popular nonparametric method is the Data Envelopment Analysis (DEA) technique which is based on the mathematical programming approach. The DEA put relatively little structure on the specification of the best practice frontier. DEA is a linear programming technique where the set of best practice or frontier observations are those for which no other decision-making unit (DMU) or linear combination of units has as much or more of every output (given inputs) or as little or less of every input (given outputs). The DEA frontier is formed as the piecewise linear combinations that connect the set of these best practice observations, yielding a convex production possibilities set. As such, DEA does not require the explicit specification of the form of the underlying production relationship. DEA permits efficiency to vary over time and makes no prior assumption regarding the form of the distribution of inefficiencies across observations except that observations that are not dominated are 100% efficient.

The nonparametric approaches impose less structure on the frontier. The nonparametric approaches, however, do not allow for random error owing to weather, strikes, luck, data problems, or other measurement errors. If random error exists, measured efficiency may be confounded with these random deviations from the true efficiency frontier. As well, statistical inference and hypothesis tests cannot be conducted for the estimated efficiency scores.

4.3 Relative merits and drawbacks of the methods

The parametric approach of stochastic production frontiers and the nonparametric approach of data envelopment analysis presented in the previous sections, along with their specific research models identified for carrying out this study, possess their own strengths and weaknesses. What is interesting and useful for this study is that they are mostly complementary; i.e., the weaknesses of one approach are oftentimes the strengths of the other approach.

The following Table 4.2 summarize the comparative merits and potential drawbacks associated with each approach.

Table 4.2 Comparison between DEA and SFA Approaches

	SFA approach	DEA approach
Strengths	♦ DEA assumes all deviations from the frontier are due to inefficiency. If any noise is present (e.g., due to measurement error, weather, strikes, etc.), then this may influence the placement of the DEA frontier and hence the measurement of productive efficiency more than would be the case with stochastic production frontiers; and ♦ tests of hypotheses regarding the existence of productive inefficiency and the structure of the production technology can be performed without difficulty in a stochastic frontier approach.	♦ it doesn't need to specify a distribution for the inefficiency part; ♦ it doesn't need to specify a functional form for the production process; ♦ it can accommodate multiple outputs; and ♦ it can include environment factors in the model.
Weaknesses	♦ the need to specify a statistical distribution for the inefficiency component; ♦ the need to specify a functional form for the production frontier; and ♦ it is more difficult to accommodate multiple outputs.	♦ measurement errors and other noise may influence the shape and position of the envelopment surface, and hence the derived scores of productive efficiency; ♦ when one has few observations and many inputs or outputs, many of the firms will appear on the DEA frontier, with perfect scores of one (curse of dimensionality).

DEA provides a comprehensive picture and evaluation of organizational performance, without the constraints and assumptions of the SFA. By Simultaneously handling multiple inputs and outputs without making judgments on their relative importance, and by not requiring the specification of a functional form for the input-output relationship, DEA offers a more complete examination of performance. Since it is difficult to find a commonly agreement upon functional form relating inputs consumed to outputs produced, the multidimensional nature of the bus transit industry makes it an idea application area for DEA.

4.4 Distance functions

The frontier efficiency measures which the present author focuses mainly on in this dissertation, are based on the concept of distance functions for multi-input and multi-output technology. One may specify both input and output distance functions. Distance functions describe multi-input and multi-output production technology without the need to specify a behaviorual objective (such as profit-maximization or cost-minimization). An input distance function characterizes the production technology by looking at a minimal proportional contraction of the input vector, given an output vector. An output distance function considers a maximal proportional expansion of the output vector, given an input vector.

4.4.1 Input and output distance functions

Following Fare and Primont (1995), the notation x and y is used to denote a non-negative $K \times 1$ input vector and a non-negative $M \times 1$ output vector, respectively. The technology set is then defined as

$$S = \{(x, y) : x \quad \textit{can produce} \quad y\} \tag{4.2}$$

That is, the set of all input-output vectors (x, y), such that x can produce y.

Given some assumptions, the input and output distance functions are defined on the input set, $L(y)$, and output set, $P(x)$, which are assumed to satisfy some properties and are redefined from the production technology set S, respectively, as:

Input distance function **Output distance function**

$$d_i(x, y) = \max\{\rho : (x/\rho) \in L(y)\} \tag{4.3}$$

$$d_0(x, y) = \min\{\delta : (y/\delta) \in P(x)\} \tag{4.4}$$

Two inputs, x_1 and x_2, and an output vector, y, are used to illustrate the input distance function in a two-dimensional diagram as shown in Figure 4.3. Here the input set, $L(y)$, is the area bounded from below by the isoquant, Isoq-$L(y)$. The value of the distance function for the point, A, which defines the production point where firm A uses x_{1A} of input 1 and x_{2A} of input 2, to produce the output vector, y, is equal to the ratio $p = \text{OA}/\text{OB}$.

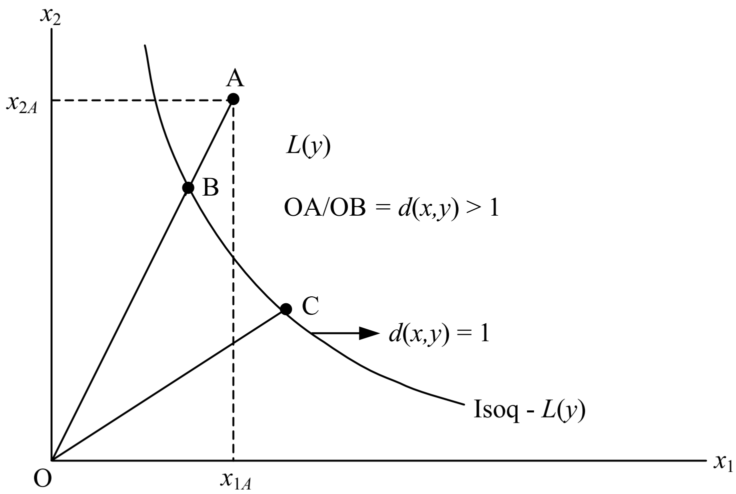

Figure 4.3 Input Distance Function and Input Requirement Set

The output distance function may be illustrated using the production possibility curve concept in a two-dimensional space as in Figure 4.4. Assuming two outputs, y_1 and y_2 are produced using the input vector, x. Thus, the production possibility set, $P(x)$, is the area bounded by the production possibility frontier, $\text{PPS} - P(x)$, and y_1 and y_2 axes. The value of the distance function for the firm using input level x to produce the outputs defined by the point A is equal to the ratio $\delta = \text{OA}/\text{OB}$. Points B and C are on the production possibility surface and hence would have distance function values equal to 1.

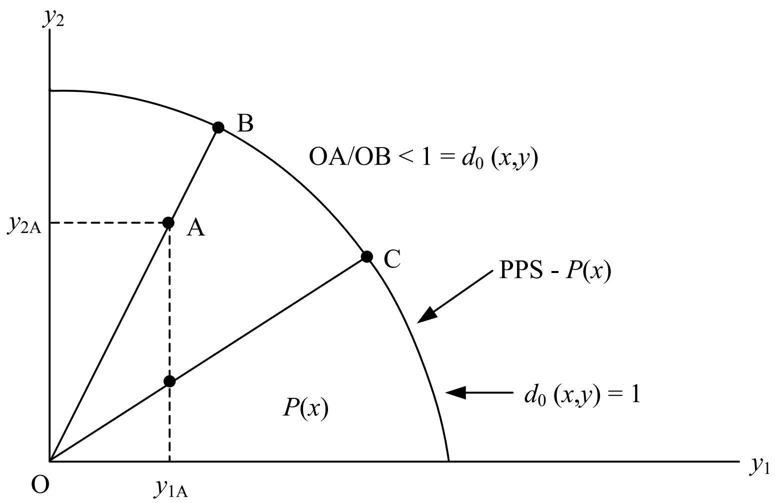

Figure 4.4 Output Distance Function and Output Requirement Set

4.5 Efficiency measurement concepts

Much of the discussion here draws on Farrell's (1957) original ideas, Coelli (1996), and Coelli et al (1998). Modern efficiency measurement begins with Farrell (1957) who drew upon the work of Debreu (1951) and Koopmans (1951) to define a simple measure of firm efficiency that could account for multiple inputs. He identified two components of a firm's efficiency: technical efficiency (TE), which reflects the ability of a firm to obtain maximal output from a given set of inputs, and price (allocative) efficiency (AE), which reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices. These two measure are then combined to derive a measure of overall (total) economic efficiency (EE).

4.5.1 Input-oriented and output-oriented measures

Farrell illustrated his ideas using a simple example involving firms that use two inputs (x_1 and x_2) to produce a single output (y), under the assumption of constant returns to scale (CRS). Specifically, it addresses the question: "By how much can input quantities be proportionally reduced without changing the output quantities produced ?" Knowledge of the unit isoquant of the fully efficient firm, represented by SS' in Figure 4.5, permits the measurement of technical efficiency. Note that the technical efficiency here is the inverse of the input distance function as defined in Figure 4.3.

If the input price ratio, represented by the line AA' in Figure 4.5 is known, allocative efficiency may also be calculated.

The output-orientated technical efficiency measure addresses the question: "By how much can output quantities be proportionally expanded without altering the input quantities used?" Output-orientated measures are then discussed by considering the case where production involves two outputs (y_1 and y_2) and a single input (x). If assuming constant

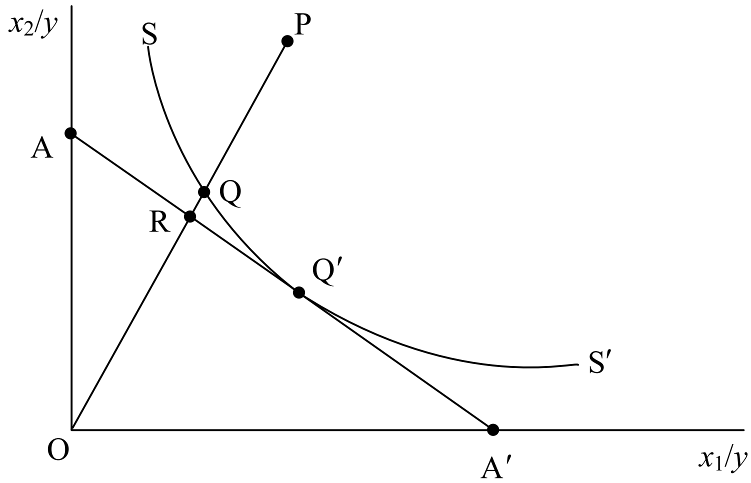

Figure 4.5 Input-oriented Technical and Allocative Efficiencies

eturn to scale, the technology can be represented by a unit production possibility frontier in two dimensions. As shown in Figure 4.6 where the line ZZ' is the unit production possibility frontier. If one has price information then one can draw the isorevenue line DD', and define the allocative efficiency.

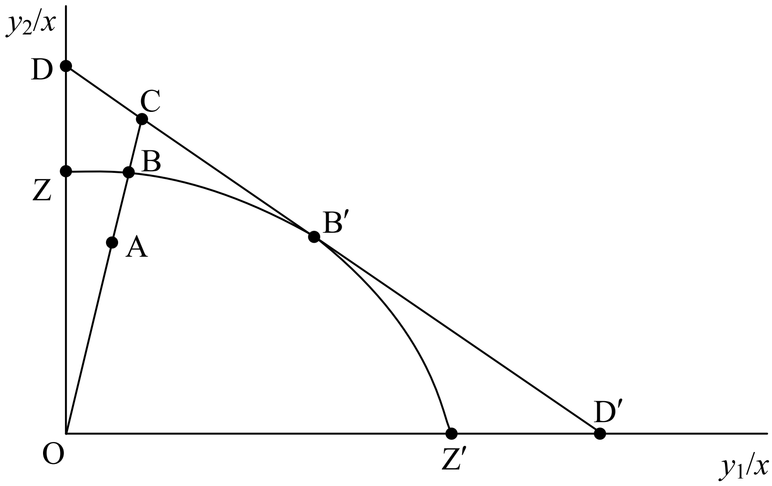

Figure 4.6 Output-oriented Technical and Allocative Efficiencies

The input-oriented and output-oriented measures are defined as:

Input-oriented

$$\mathrm{TE_i} = \mathrm{OQ/OP}$$

$$\mathrm{AE_i} = \mathrm{OR/OQ}$$

$$\mathrm{EE_i} = \mathrm{TE_i} \times \mathrm{AE_i} = \mathrm{OR/OP} \qquad (4.5)$$

Output-oriented

$$\mathrm{TE_0} = \mathrm{OA/OB}$$

$$\mathrm{AE_0} = \mathrm{OB/OC}$$

$$\mathrm{EE_0} = \mathrm{TE_0} \times \mathrm{AE_0} = \mathrm{OA/OC} \qquad (4.6)$$

All the above efficiency measures lie between zero and one. A value of one indicates the firm is fully technically (or allocatively or economically) efficient. It is also worth noting the following points about all the efficiency measures discussed above. All are measured along a ray from the origin to the observed production point. Hence they hold the relative proportions of inputs (or outputs) constant. One advantage of these radial efficiency measures is that they are unit invariant. That is, changing the units of measurement (e.g., measuring vehicle age in kilo-meters instead of years) will not change the value of the efficiency measure. The Farrell input-and output-orientated technical efficiency measures can be shown to be equal to the input and output distance functions discussed in Shephard (1970).

4.6 Basic concept of DEA method

Broadly speaking, DEA evaluates efficiency by reference to the best use of resources that other comparable production units are observed to make, the so-called “best-practice” frontier.

Data envelopment analysis (DEA) involves the use of linear programming methods to construct a non-parametric piecewise surface (or frontier) over all data, so as to be able to calculate efficiencies relative to this surface. The DEA is based on the piecewise-linear convex hull approach to frontier estimation originally proposed by Farrell (1957). Charnes, Cooper and Rhodes (1978) proposed a so called CCR model that had an input orientation and assumed constant returns to scale (CRS). Banker, Charnes and Cooper (1984) extended the model by imposing a variable returns to scale (VRS) assumption, usually termed BCC model. Following is a description of the basic DEA model.

DEA can be thought of as an empirical specification of activity analysis, which is itself a piecewise-linear specialization of the general notion of a production possibility set or technology.

All DEA models begin with the idea of input and output bundles, which are assumed to satisfy the following four assumptions. First, they are non-negative. Second, there is at least one feasible input-output pair, that is, the production possibility set S is non-empty. Third, the production possibility set S (and hence the input set, $L(y)$, and the output set, $P(x)$) contain their boundaries. This implies that all three sets contain efficient input-output combinations, or that the production frontier exists. Finally, in order to produce strictly positive quantities of at least one output, strictly positive quantities of at least one input are need, the assumption of "no free lunch."

Under these assumptions, activity analysis constructs the set S of all feasible input-output combinations by focusing on an initially given finite set of J feasible combinations – the so-called "basic activities" –and building up additional feasible activities as linear combinations of these. The basic activities are combined into new feasible activities by means of a non-negative "intensity vector" $z = (z_1, z_2, ..., z_J)$ representing the permissible expansions or contractions of the basic activities. The result is a piecewise linear technology. Depending on the intensity vector, different linear combinations of the basic activities are admitted into (or excluded from) the production possibility set S.

DEA specialize activity analysis in two respects. First, it focuses on "actual practice" in an industry by taking the "basic activities" to be a set of observed input-output combinations. Second, DEA is concerned with the "best" practice. This is implemented by taking S to be the set that "most tightly" envelops the observed data. That is, the smallest set S that includes all the data.

4.6.1 The constant returns to scale (CRS) DEA model

This section begins by defining some notations. Assume there are data on K inputs (denoted by the vector x_i) and M outputs (denoted by the vector y_i) on each of N

firms or decision-making units (DMUs) as they are called in the DEA literature. The $K \times N$ input matrix, X, and the $M \times N$ output matrix, Y, represent the data of all N firms. The purpose of DEA is to construct a non-parametric envelopment frontier over the data points such that all observed points lie on or below the production frontier. For the simple example of an industry where one output is produced using two inputs, it can be visualized as a number of intersecting planes forming a tight cover over a scatter of points in two-dimensional space. Given the constant returns assumption, this can be represented by a unit isoquant in input/input space (see Figure 4.5).

The easiest way to introduce DEA is via the ratio form. For each DMU one would like to obtain a measure of the ratio of all outputs over all inputs, such as $u'y_i / v'x_i$, where u is an $M \times 1$ vector of output weights and v is a $K \times 1$ vector of input weights. To select optimal weights, one can specify the mathematical programming problem:

$$max_{u,v}\left(u'y_i / v'x_i\right),$$

$$\text{st} \quad u'y_i / v'x_i \leq 1, \quad i = 1,2,...,N$$

$$u, v \geq 0 \tag{4.7}$$

This involves finding values for u and v such that the efficiency measure of the i-th DMU is maximized, subject to the constraint that all efficiency measures must be less than or equal to one. One problem with this particular ratio formulation is that it has an infinite number of solutions. That is, if (u^*, v^*) is a solution, then $(\alpha u^*, \alpha v^*)$ is another solution, etc. To resolve this problem, one can convert it into linear form so that the methods of linear programming can be applied. For the objective function it is necessary to observe that in maximizing a fraction or ratio, it is the relative magnitude of the numerator and denominator that are of interest and not their individual values. It is thus possible to achieve the same effect by setting the denominator equal to a constant and maximizing the numerator. Imposing the constraint $v'x_i = 1$, the linear program becomes:

$$\max_{u,v}\left(\mu' y_i\right),$$

$$\text{st} \quad \nu' x_i = 1$$

$$\mu' y_j - \nu' x_j \le 0, \quad j = 1,\ldots,N$$

$$\mu, \nu \ge 0 \tag{4.8}$$

where the notation change from u and v to μ and ν reflects the transformation. This form is known as the multiplier form of the linear programming problem. Using duality, one can derive an equivalent envelopment form of this problem as:

Input-oriented

$$min_{\theta,\lambda}\theta,$$

$$\text{st} \quad -y_i + Y\lambda \ge 0$$

$$\theta x_i - X\lambda \ge 0$$

$$\lambda \ge 0 \tag{4.9}$$

Output-oriented

$$\max_{\phi,\lambda}\phi,$$

$$\text{st} \quad -\phi y_i + Y\lambda \ge 0$$

$$x_i - X\lambda \ge 0$$

$$\lambda \ge 0 \tag{4.10}$$

where θ is a scalar and λ is a $N \times 1$ vector of constants. This envelopment from involves fewer constraints than the multiplier form ($K + M < N + 1$), and hence is generally the preferred form to solve. The value of θ (or ϕ)obtained will be the efficiency score for the i-th DMU. It will satisfy θ (or ϕ)≤ 1, with a value of 1 indicating a point on the frontier and hence a technically efficient DMU, according to the Farrell (1957) definition. Note that the linear programming problem must be solved N time, once for each DMU in the sample. A value of θ (or ϕ) is then obtained for each DMU.

4.6.2 The variable returns to scale (VRS) and scale efficiencies

The constant returns to scale (CRS) assumption is only appropriate when all DMUs are operating at an optimal scale, that is, one corresponding to the flat portion of the long-run average cost curve. Imperfect competition, constraints on finance, government regulation, subsidies, etc., may cause a DMU to be not operating at optimal scale. Banker et al. (1984) suggested an extension of the constant returns to scale DEA model to account for variable returns to scale (VRS) Situations. The use of the constant returns to scale specification when not all DMU's are operating at the optimal scale will result in measures of technical efficiency that are confounded by scale efficiencies (SE). The variable returns to scale assumption permits the calculation of technical efficiency devoid of these scale efficiency effects.

The constant returns to scale linear programming problem can be modified to account for variable returns to scale by adding the convexity constraint $N1'\lambda = 1$ to the envelopment form as:

Input-oriented

$$\begin{aligned} & min_{\theta,\lambda}\theta, \\ \text{st} \quad & -y_i + Y\lambda \geq 0 \\ & \theta X_i - X\lambda \geq 0 \\ & N1'\lambda = 1 \\ & \lambda \geq 0 \end{aligned} \tag{4.11}$$

Output-oriented

$$\begin{aligned} & max_{\phi,\lambda}\phi, \\ \text{st} \quad & -\phi y_i + Y\lambda \geq 0 \\ & X_i - X\lambda \geq 0 \\ & N1'\lambda = 1 \\ & \lambda \geq 0 \end{aligned} \tag{4.12}$$

where $N1$ is an $N \times 1$ vector of ones. This approach forms a convex hull of intersecting planes which envelope the data points more tightly than the constant returns to scale conical hull and thus provides technical efficiency scores which are greater than or equal to those obtained using the constant returns to scale model. The variable returns to scale specification has been the most commonly used in the 1990s.

The variable returns to scale model allow one to obtain a scale efficiency measure for each DMU. If there is a difference in the CRS and VRS technical efficiency scores (the point estimates) for a particular DMU, then this indicates the DMU has scale inefficiency.

The scale inefficiency can be calculated from the difference between the VRS and CRS technical efficiency scores. Specifically, the scale efficiency is the ratio of the CRS technical efficiency scores to the VRS technical efficiency scores. This measure of scale efficiency, however, does not indicate whether the DMU is operation in an area of increasing or decreasing returns to scale.

One can identify increasing and decreasing returns to scale by running an additional DEA problem with non-increasing returns to scale (NIRS) assumption imposed. This is done by modifying the convexity constraint as $N1'\lambda \leq 1$, to provide:

Input-oriented

$$\begin{aligned} & min_{\theta,\lambda}\theta, \\ \text{st} \quad & -y_i + Y\lambda \geq 0 \\ & \theta x_i - X\lambda \geq 0 \\ & N1'\lambda \leq 1 \\ & \lambda \geq 0 \end{aligned} \qquad (4.13)$$

Output-oriented

$$\begin{aligned} & max_{\phi,\lambda}\theta \\ \text{st} \quad & -\phi y_i + Y\lambda \geq 0 \\ & x_i - X\lambda \geq 0 \\ & N1'\lambda \leq 1 \\ & \lambda \geq 0 \end{aligned} \qquad (4.14)$$

The nature of scale inefficiencies, that is, due to increasing or decreasing returns to scale, for a particular DMU can be determined by comparing the point estimates of the NIRS technical efficiency score to the point estimates of the VRS technical efficiency score. If they are equal, then the DMU experience decreasing returns to scale (DRS); and if they are unequal, then the DMU experience increasing returns to scale (IRS). Also, if the technical efficiency scores (point estimates) under both CRS and VRS assumptions are equal, then the DUM experiences a constant returns scale technology.

4.6.3 Price information and allocative efficiency

As mentioned in the previous sections, if price information is available and a behavioural objective, such as cost minimization or revenue or profit maximization, is appropriate, then it is possible to measure allocative efficiencies as well as technical efficiencies. To achieve this, two sets of linear programs are required; one to measure technical efficiency and the other to measure economic efficiency. The allocative efficiency measure is then obtained residually as described in the previous section. The procedure using the cost minimization case is now illustrated below.

4.6.3.1 Cost minimization

For the case of VRS cost minimization, the input-orientated DEA model, defined in equation 4.11, is conducted to obtain technical efficiencies (TE). The next step requires the solution of the following cost minimization DEA:

$$min_{\lambda,x_i^*} w_i' x_i^*,$$

$$\text{st} \quad -y_i + Y\lambda \geq 0,$$

$$x_i^* - X\lambda \geq 0,$$

$$N1'\lambda = 1$$

$$\lambda \geq 0, \qquad (4.15)$$

where w_i is a vector of input prices for the i-th firm and x_i^* (which is calculated by the LP) is the cost-minimizing vector of input quantities for the i-th firm, given the input prices w_i and the output levels y_i. The total cost efficiency or economic efficiency (EE) of the i-th firm is calculated as

$$\text{EE} = w_i' x_i^* / w_i' x_i \qquad (4.16)$$

That is, EE is the ratio of minimum cost to observed cost for the i-th firm.

The allocative efficiency is calculated residually by

$$\text{AE} = \text{EE}/\text{TE} \qquad (4.17)$$

Note that this procedure implicitly includes any slacks into the allocative efficiency measure. This is often justified on the grounds that slacks reflects inappropriate input mixes.

4.6.3.2 Revenue maximization

If revenue maximization is a more appropriate behavioural assumption, then allocative inefficiency in output mix selection can be accounted for in a similar manner. For the case of VRS revenue maximization, technical efficiencies are calculated by solving the output-orientated DEA model, defined in equation 4.12. The following revenue maximization DEA problem is then solved,

$$max_{\lambda,y_i^*} p_i' y_i^*,$$

$$\text{st} \quad -y_i^* + Y\lambda \geq 0,$$

$$x_i^* - X\lambda \geq 0,$$

$$N1'\lambda = 1$$

$$\lambda \geq 0, \qquad (4.18)$$

where p_i is a vector of output prices for the i-th firm and y_i^* (which is calculated by the LP) is the revenue-maximizing vector of output quantities for the i-th firm, given the output prices p_i and the input levels x_i. The total revenue efficiency of economic efficiency (EE) of the i-th firm is calculated as

$$\text{EE} = p_i' y_i / p_i' y_i^* \qquad (4.19)$$

That is, EE is the ratio of observed revenue to maximum revenue. The (output) allocative efficiency measure is obtained residually using equation (AE = EE/TE).

Cost minimisation and revenue maximisation together imply profit maximisation. Only a handful of studies have considered profit efficiency using DEA methods. Fare et al. (1997)

suggest solving two sets of linear programs. The first involves a profit maximizing DEA to measure profit efficiency and the second DEA is one in which technical efficiency is measured as a simultaneous reduction in the input vector and expansion of the output vector. This technical efficiency measure uses what are known as directional distance functions, which is applied in this dissertation.

4.7 Environmental factors in DEA analysis

Besides the conventional inputs and outputs, there are other factors that could impact the technical efficiency of transit systems. The term environment is used to describe factors that could influence the efficiency of a firm (DMU), where such factors are not traditional inputs (or outputs) and are assumed not under the control of the manager. Environmental factors may be measured directly or through the use of surrogate measures. Environmental variables include

1. ownership differences, such as public/private or corporate/non-corporate;
2. location characteristics, such as schools influenced by socioeconomic status of children and city/country location, or electric power distribution networks influenced by population density and average customer size;
3. labour union power; and
4. government regulations, etc.

There are a number of ways in which environmental variables can be accommodated in a DEA study (see Coelli et al, 1998, for details).

More recently, another so called three-stage methodology is developed by Fried et al. (2002). They propose a new technique for incorporating environmental effects and statistical noise into a producer performance evaluation based on DEA. The technique involves a three-stage analysis. In the first stage, DEA is applied to outputs and inputs only, to obtain initial measures of producer performance. In the second stage, SFA is used to regress first stage performance measures against a set of environmental variables. This provides, for each input or output (depending on the orientation of the first stage DEA model), a three-way decomposition of the variation in performance into a part attributable to environmental effects, a part attributable to managerial inefficiency, and a part attributable to statistical noise. In the third stage, either inputs or outputs (again depending on the orientation of the first stage DEA model) are adjusted to account for the impact of the environmental effects and the statistical noise uncovered in the second stage, and DEA is used to re-evaluate producer performance. Throughout the analysis emphasis is placed on slacks, rather than on radial efficiency scores, as appropriate measures of producer performance.

CHAPTER 5

The Case Study 1

─ The Effects of Privatization on Return to the Dollar: A Case Study on Technical Efficiency and Price Distortions of Taiwan's Intercity Bus Services

5.1 Introduction

In the preceding input-oriented and output-oriented models, discussed in Section 4.4, the input oriented measure of technical efficiency seeks to identify a scalar by which one can equiproportionately scale down (contract) the inputs with output levels held constant, while the output oriented measure of technical efficiency searches for a scalar by which one can scale up (expand) the outputs with input levels held fixed. In order to allow for simultaneous scaling of inputs and outputs, or desirable and undesirable outputs, Fare et al. (1985, 1994) introduced the hyperbolic approach to efficiency measurement. This approach allows for a simultaneous and equiproportionate expansion of outputs and contraction of inputs (or undesirable outputs), and thus, performs simultaneously what the above input-oriented and output-oriented measures do.

However, as mentioned before, it appears that most of previous measurements in relation to performance focus on technical efficiency (TE), where either an input-oriented technical efficiency measure or output-oriented technical efficiency measure, or both were applied, while ignoring any measure of allocative efficiency (AE). Further, there have been relatively few attempts to apply the hyperbolic approach to efficiency measurement and to look further at allocative efficiency to measure price distortions in the bus transportation market.

Based on production frontier methodologies, the production efficiency of a firm is often measured by fitting an upper-envelope profit function or a lower-envelope cost function to a firm's price and production data. The assumption of profit maximization implies that "best-practice" production plans are, in the ideal, technically efficient; that is to say, they are located on the boundary of the set of inputs required to produce any given set of outputs. In addition, profit maximization requires that "best-practice" plans be allocatively efficient, which is to say that out of all technically efficient plans, the allocatively efficient plans maximize profit at their given prices (Hughes, 1999). A variety of parametric and non-parametric techniques are available for computing the best practice frontier. Recall that Farrel (1957) proposes that the efficiency of a firm consists of two components: technical efficiency, which reflects the ability of a firm to obtain maximal output from a given set of inputs, and allocative efficiency, which reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices and the production technology. These two measures are then combined to provide a measure of overall (total) economic efficiency.

In this framework for measuring efficiency, the role of input and output prices is to aggregate production plans into a money metric that permits their ranking by relative efficiency or, equivalently, by their respective distances from the best-practice frontier. On the other hand, when information on each input price and output price are not available, allocative efficiency cannot be estimated. This paper argues that these cases that lead to information on prices being unavailable pose a serious problem for the standard techniques of efficiency measurement, and their alternative pricing strategies influence a firm's profit margin through their effect both on expected profits and on the discount rate applied to those profits'effects that are not taken into account by the standard techniques of efficiency measurement. To solve these two problems, this paper turns to an alternative technique of efficiency measurement which was proposed by Färe et al. (2002), based on a model of production developed by Chambers et al. (1998). This alternative gauges efficiency relative to frontiers that are not conditioned on prices and hence account for the efficiency of different pricing strategies. These techniques are described in some detail to analyze how their measures of efficiency differ and how they are related to the profit margins of firms. To illustrate the importance of accounting for price distortion in measuring efficiency, this alternative model is employed to study how differences in pricing strategies affect the profit margin of the firms before and after privatization.

Färe et al. (2002) establish the relations between a hyperbolic graph measure of technical efficiency and the radial measures of technical efficiency and show that the dual cost and revenue interpretation of the hyperbolic efficiency measure are related to Georgescu-Roegen's (1951) notion of "Return to the dollar". Once this relation is established, it leads to a derivation of an allocative efficiency index, which measures price distortions using data on observed costs and revenues without requiring explicit information on prices.

Using station-level data composed of 15 stations for the years 2000 and 2002, the goal of this study is to analyze the impact of the privatization on "return to the dollar" change by investigating both the technical efficiency and price distortion changes of the TMTC and KKTC operations.

The impact of privatization has resulted in an improved financial performance by KKTC. Prior to privatization, TMTC's 15 subsidiaries (stations) had returned losses in aggregate for each year between 1996 and 2000. The 2000 accounts show a loss for TMTC of $5.5 million on a turnover of $90 million.

There is little useful data available from which one can infer the financial performance of KKTC's transit activities. Its annual accounts of 2002 show a gross revenue of $81.7 million for the entire network, but give no details about patronage other than saying it continues to grow. On the other hand, KKTC created new labor terms and conditions and then with the help of government bought out the old terms and conditions so as to create a cost structure which was capable of competing properly against the other low-cost independent operators in the transportation market. This resulted in a decline of real wage rates, up to 60% that of TMTC on average.

Prior to privatization there had been single, day return and period return fares with a 10% reduction for passengers. Discriminatory pricing by day was immediately established following privatization, in response to competition from other incumbent operators and the railway. This more heavily-discounted rate, set at around 70% of two single fares at the pre-privatization level, was only available for passengers making both legs of their journey on a Monday (after midday), Wednesday, Thursday, and Friday (before midday), i.e. the times of the greatest spare capacity. This change in price structure was based on the concept of elastic demand where fare reductions increase traffic sufficiently to increase revenue.

Aside from describing the operating changes of SOE and the POE response to privatization which ultimately resulted in a profit increase in the POE, this study seeks to identify:

1. whether or not technical efficiency improved following privatization; and
2. to what extent price distortions were created under each ownership type.

5.2 Model formulation

5.2.1 The hyperbolic graph measure

As indicated by Fielding (1987), cost effectiveness measures the relationship between input and consumed service such as passenger-kilometer or passenger trips. It is concerned with demand-side relationships. Assume that one is interested in cost effectiveness, this requires that one simultaneously adjusts input and output quantities, since one wishes to increase output quantities and decrease input quantities concurrently. A technology with a hyperbolic graph efficiency approach which seeks the maximum simultaneous equiproportionate expansion for the output and contraction for the inputs is modeled here. In contrast to radial contractions or expansions of observed data, the model introduced here is a hyperbolic path to the frontier of technology.

To measure technical efficiency, one can follow Fare et al's (1985, 1994) hyperbolic Farrell measure. Let $y \in R^{M+}$ and $x \in R^{N+}$ denote respectively vectors of outputs produced and inputs employed by an individual station which represents a decision making unit (DMU) in this study. The graph reference set, $T(x, y) = \{(x, y) : x \text{ can produce } y\}$, satisfies constant returns to scale (CRS) and the strong disposability of inputs and outputs. The hyperbolic graph measure of technical efficiency is defined as:

$$F_g(x, y) = \min\{\lambda : (\lambda x, y/\lambda) \in T\}. \tag{5.1}$$

The term graph is indicated by the subscript g. If $F_g(x, y) = 1$, then the firm operates on the frontier of $T(x, y)$, while $F_g(x, y) < 1$ indicates that the firm operates inside $T(x, y)$. Following Fare et al. (1985, 1994) the input-oriented Farrell measure is defined as $F_i(x, y) = \min\{\lambda : (\lambda x, y) \in T\}$, with the input measure $F_i(x, y)$ equal to the square of the hyperbolic measure $F_g(x, y)$ (see Fare et al. (2002) for more details in such a relationship). The reciprocal of $F_i(x, y)$ serves as the output-oriented Farrell measure $F_o(x, y)$ if and only if technology exhibits CRS. Thus, CRS implies

$$(F_g(x, y))^2 = F_i(x, y), \tag{5.2}$$

$$(F_g(x, y))^2 = \frac{1}{F_o(x, y)} \tag{5.3}$$

Those stations that are able to minimize the proportional or scaling factor λ, relative to other stations, are considered perfectly efficient and are thus found on the "best practice frontier" with a λ-value of "1". Those firms which are less efficient are found at some distance from the frontier, with that distance being the basis for measuring their inefficiency;

the λ-value of these stations will be "less than 1". Figure 5.1 illustrates the case with only one input and one output. Given observed (x_j, y_j), $F_g(x_j, y_j)$ simultaneously expands y_j and contracts x_j at the same rate, following the hyperbolic path shown in the Figure 5.1. In contrast, the $F_i(x_j, y_j)$ measure of input technical efficiency contracts x_j following the horizontal path to the graph. The $F_o(x_j, y_j)$ measure of output technical efficiency expands y_j to the graph, holding x_j fixed, i.e., following the vertical path to the graph.

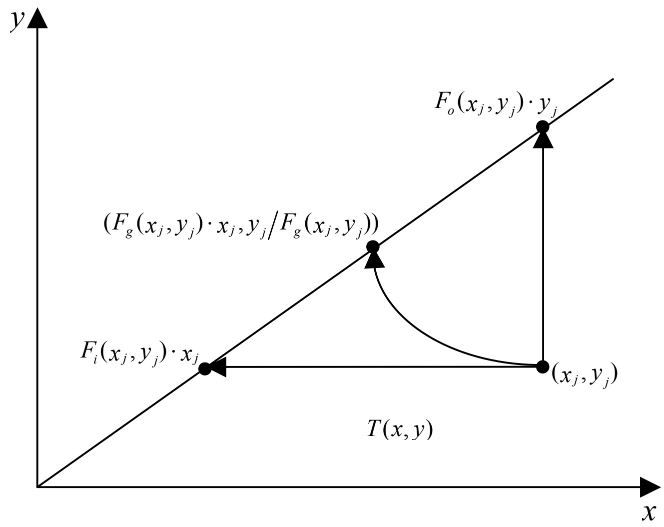

Figure 5.1 Comparison of Hyperbolic, Input, and Output Measures of Technical Efficiency

5.2.2 "Return to the dollar" and the hyperbolic graph measure

If one knows the prices of the inputs w_s and the outputs p_s, then one can measure overall efficiency as follows:

$$O_g(x, y, w, p) = A_g(x, y, w, p) \cdot F_g(x, y, w, p), \tag{5.4}$$

where $A_g(\cdot)$ denotes the allocative efficiency. It is difficult to know all of the input and output prices of each station in detail, but it is easier to obtain the observed revenue and observed cost. Thus, the hyperbolic measure is related to "return to the dollar" which can be seen as the dual to the hyperbolic technical efficiency measure (Färe et al., 2002).

Let $w \in R^{N++}$ represent the set of strictly positive input prices and $p \in R^{M++}$ output prices. With this additional information, the maximum profit can be defined as follows:

$$\pi(p,w) = \max\{py - wx : (x,y) \in T\}, \tag{5.5}$$

Thus, one can

$$\pi(p,w) \geq py - wx \quad \text{for all} \quad (x,y) \in T, \tag{5.6}$$

since $\left(xF_g(x,y), y/F_g(x,y) \in T\right)$, one has

$$\pi(p,w) \geq py/F_g(x,y) - F_g(x,y)wx \tag{5.7}$$

However, the maximum feasible profit π^* is equal to zero.

Following Färe et al. (2002) the dual relationship between the hyperbolic graph measure and "return to the dollar" is defined as:

$$\frac{py}{wx} \leq \left(F_g(x,y)\right)^2 \tag{5.8}$$

In order to derive a graph measure analog of the "return to the dollar", one must introduce Georgeson-Roegen's "return to the dollar" measure py/wx, where py represents observed revenue and wx stands for observed cost. There is no need to know input or output prices in calculating the "return to the dollar".

Following Farrell (1957) the allocative efficiency can be defined as a residual, i.e. the value of the allocative efficiency measure is

$$AE = \frac{py}{wx}\frac{1}{\left(F_g(x,y)\right)^2} \tag{5.9}$$

thus

$$\frac{py}{wx} = AE \cdot TE. \tag{5.10}$$

The technical efficiency component TE equals $\left(F_g(x,y)\right)^2$, given an indication of how well resources are being managed, since it represents the gap between the DMU and the best practice frontier. This takes values between zero and one. The allocative measure AE gives an indication of the appropriateness of the mix of inputs. On the other hand, AE can also be rearranged as

$$AE = \frac{p(y/F_g(x,y))}{w(xF_g(x,y))} = \frac{p\hat{y}}{w\hat{x}} \tag{5.11}$$

where $\hat{y} = y/F_g(x,y)$ and $\hat{x} = xF_g(x,y)$ are technically efficient quantities of outputs and inputs, respectively. If prices $\hat{p}$ and $\hat{w}$ support $\hat{y}$ and $\hat{x}$, then $AE = \hat{p}\hat{y}/\hat{w}\hat{x} = 1$, and AE can also be written as

$$AE = \left(\frac{p\hat{y}}{\hat{p}\hat{y}} \bigg/ \frac{w\hat{x}}{\hat{w}\hat{x}} \right) = \left(\frac{\sum p_m \hat{y}_m}{\sum \hat{p}_m \hat{y}_m} \bigg/ \frac{\sum w_n \hat{x}_n}{\sum \hat{w}_n \hat{x}_n} \right) \tag{5.12}$$

The term AE represents the short-run prices p deviating from their optimal long-run values $\hat{p}$ with respect to the short-run prices w that deviate from their optimal long-run values $\hat{w}$. Since AE is computed in reference to the "return to the dollar" which may take a value bigger or smaller than one, AE may also take values smaller or bigger than one. If the value of AE is greater than one, then it implies the ability to distort output prices at higher rates than input prices (Fare et al. 2002).

Since this is an index based on discrete time, each station here will have an index for each year. This entails calculating the hyperbolic efficiency incorporating an environmental variable as well as using linear programming methods. In the interest of simplicity, however, neither the complete picture of the complexity inherent in the station efficiency problem being modeled and conveyed in Figure 5.1, nor the working of constraints expressing the existence of an environmental variable (non-discretionary input), are depicted in the graph. Nonetheless, such constraints are used in this modeling effort in order to "control" for the service area population of the station effort faced by each station. Since contraction does not take place along these dimensions, comparisons of "like-to-like", in the form of service area population, are facilitated by the model.

The hyperbolic measure of technical efficiency, $F_g(x,y)$, for each DMU is calculated by solving the following linear program:

$$F_g^{k'}(x,y) = \min \lambda^{k'} \tag{5.13a}$$

$$\text{st} \quad \sum_{k=1}^{K} z_k y_m^k \geq y_m^{k'} / \lambda^{k'}, m = 1,\cdots,M, \tag{5.13b}$$

$$\sum_{k=1}^{K} z_k x_n^k \leq \lambda^{k'} \cdot x_n^{k'}, n = 1,\cdots,N, \tag{5.13c}$$

$$\sum_{k=1}^{K} z_k e_p^k \leq e_p^{k'}, p = 1,\cdots,P, \tag{5.13d}$$

$$z_k \geq 0, k = 1,\cdots,K \tag{5.13e}$$

In this example, firm k' is an observed station and λ is the "contraction" factor corresponding to the level of efficiency. One can assume that there are $k = 1,\cdots,K$ stations with $p = 1,\cdots,P$ environmental variables which use $n = 1,\cdots,N$ inputs to produce $m = 1,\cdots,M$ outputs. z_k is an intensity variable.

5.3 The data

Data on inputs and outputs were drawn from both TMTC's and KKTC's annual statistical reports and accounts and were supplemented by further data requested from both operators. Since both TMTC and KKTC were undoubtedly undergoing a degree of "privatization turmoil," characterized by a fundamental shake-up, business or working practices changing, and employees entering and leaving the firms, the data for the year of privatization (i.e., 2001) was excluded to avoid any possible bias. In addition, no significant reforms appear to have taken place after the year of structural change in the KKTC. Therefore, the TMTC station-level data during the period of 2000 and the KKTC data for the period of 2002 can be used. Moreover, a desirable feature of the data is that except in a few cases, both public and private activities co-exist allowing for a comprehensive analysis of relative distortions created by each ownership type (Färe et al., 2002).

The wild variability in the use of inputs and outputs in transit technology specifications has been reviewed by De Borger et al. (2002). They indicate that this variability simply suggests that there is generally no accepted set of relevant variables in the bus industry. In this study, for each DMU (station) in the sample, therefore four traditional inputs for the assessment of efficiency can be used, which are measured in physical units: fleet size (x_1), which is taken to be the total number of vehicles operated at maximum service, number of employees (x_2), number of liters of fuel used (x_3), and network length (x_4). The quantity of passenger-kms (y) for the measurement of efficiency is taken as the single measure of output. A further series, differences in service area population (e) of each DMU, was added to these measures as an environmental (input) variable to reflect the differences in potential demand impacting on intercity service outputs, but outside of the control of the station management. The intention was to prevent DMUs in remote areas from being disadvantaged in an assessment of relative efficiency over time. All these input and output data constitute the terms x_n, y_m, and e_p of the previous section.

The whole sample therefore consists of the 15 stations (denoted by S1~S15) of both TMTC and KKTC, for which all the input and output data were available over the 2000-2002 period (excluding the data of 2001). All these related data are used to calculate the comparison of the before and after effects of privatization on efficiency. In the interest of analysis, however, these 15 stations can be divided into three groups based on the geographical characteristics of the area in which bus stations operate. Such information would probably help explain some of the differences found in the performance between stations of the different regions; that is, the northern (N) region including seven stations (S1~S7), the central (C) region including three stations (S8~S10), and the southern (S) region including five stations (S11~S15). Moreover, the measure of the profit rate is the ratio of operating revenues to the operating costs as measured by the total cost of all the inputs including administrative, driver and mechanics wages, fuel expenses, and maintenance costs.

A preliminary examination of summary data before and after privatization reveals the operating changes that have been instituted at TMTC and KKTC, as well as the market response to their service offers (Table 5.1). In terms of resources, KKTC has cut the number of employees by 44%, the number of vehicles by 36%, the liters of fuel used by 24%, and the network length by 22% as compared to TMTC over the study period. On average regions had a population of 1,467,232 with a standard deviation of 1,232,266 in 2002. Although the number of service area population has slightly increased by 1.1%, the amount of desired outputs of passenger-kilometers has decreased by 12%.

Table 5.1 Data Summary for TMTC and GGBC by Station Type

Station	Employees (persons)	Fleet (vehicles)	Fuel (10^3 liters)	Network length (km)	Service area population (10^3 persons)	Passenger kilometers (10^3)
TMTC (2000)						
N	198.3	87.0	3,967.6	1,390.8	1,395,311.1	166,420.9
	(99.8)	(39.0)	(2,926.3)	(1,411.3)	(1,597,634.1)	110,368.3
C	264.0	113.7	4,410.0	1,847.9	1,571,147.0	166,170.3
	(149.3)	(50.2)	(2,777.8)	(1,024.1)	(1,181,672.7)	121,747.7
S	161.8	60.6	2,498.8	1,250.5	1,458,472.4	96,731.4
	(98.9)	(28.7)	(1,423.8)	(601.6)	(824,085.1)	53,581.9
All	199.3	83.5	3,566.5	1,435.5	1,451,532.1	143,140.9
	(107.9)	(40.4)	(2,447.7)	(1,075.4)	(1,221,505.6)	96,499.5
GGBC (2002)						
N	144.3	73.6	3,405.0	1,280.4	1,417,748.7	168,626.7
	(88.0)	(38.6)	(2,274.0)	(1,457.6)	(1,608,158.0)	110,845.0
C	100.7	40.0	2,439.0	1,180.8	1,588,476.3	112,323.3
	(106.1)	(39.9)	(2,707.3)	(617.3)	(1,206,601.0)	108,799.6
S	74.0	33.8	1,859.0	922.3	1,463,762.0	73,558.2
	(41.9)	(19.7)	(1,324.5)	(542.9)	(831,955.7)	49,984.8
All	112.1	53.6	2,696.5	1,141.1	1,467,232.0	125,676.5
	(80.6)	(36.8)	(2,068.9)	(1,037.5)	(1,232,265.8)	97,986.1
Index numbers*						
N	72.8	84.6	85.8	92.1	101.6	101.3
C	38.1	35.2	55.3	63.9	101.1	67.6
S	45.7	55.8	74.4	73.8	100.4	76.0
All	56.3	64.2	75.6	79.5	101.1	87.8

Note: (1) The value in the parenthesis represents standard deviation.

(2) * With 2000 levels=100.

When these figures are viewed by station type, different patterns emerge. Employee reductions are deepest in the stations of the central (C) region (62%), with the stations of the southern (S) region sustaining about half the men, and followed by the stations of the northern (N) region with a 27% decrease following privatization. A similar pattern can be seen for fleet size and fuel use. Similarly, different station types experienced different market responses. The stations of the northern (N) region not only give the highest average passenger-kilometers, but also the only increase in passenger-kilometers over this time period (1.3%). This increase in service of the stations in the northern region, however, is marked by a substantial decrease in the amounts of the central (C) region (32%) and the southern (S) region (23%).

Given these changes in input resources and differential output production levels, the question becomes one of assessing the appropriateness of management's response to market conditions. Specifically, the question is twofold: First, can the firm's operating revenue afford to cover the operating cost ? Second, what is the origin of the "return to the dollar"?

5.4 Results and discussions

Based on the models for measuring "return to the dollar", technical efficiency and allocative efficiency shown in equation (5.9), the changes at the station-level of TMTC before and after privatization were evaluated according to the pre-selected indicators described in the previous section. Then technical efficiency and allocative efficiency are measured, and can be gauged further the extent of distortions created in the bus service market. Lastly, the origin of "return to the dollar" is tried to be identified; that is, from TE or AE?

Looking first at Table 5.2, there is a considerable discrepancy between profit margins before and after privatization. Despite the privatized firm having an average profit margin

Table 5.2 Decomposition of "Return to Dollar"

Station	TR/TC		Technical efficiency		Allocative efficiency	
	Rating	Rank	Rating	Rank	Rating	Rank
TMTC (2000)						
S1	0.767	8	0.688	12	1.114	6
S2	1.048	3	0.897	7	1.168	4
S3	1.560	1	0.960	5	1.625	1
S4	0.497	14	0.799	9	0.621	15
S5	0.489	15	0.710	10	0.689	13
S6	1.249	2	0.988	3	1.264	3
S7	0.996	4	0.982	4	1.014	8
S8	0.995	5	0.707	11	1.407	2
S9	0.689	10	0.982	4	0.702	12
S10	0.761	9	0.838	8	0.908	10
S11	0.927	6	0.997	2	0.930	9
S12	0.773	7	0.676	13	1.144	5
S13	0.669	12	0.998	1	0.671	14
S14	0.684	11	0.953	6	0.718	11
S15	0.649	13	0.624	14	1.040	7
Geometric mean	**0.810**		**0.842**		**0.961**	
GGBC (2002)						
S1	0.973	10	1.000	1	0.973	14
S2	1.152	5	1.000	1	1.152	8
S3	1.073	7	0.919	5	1.167	7
S4	1.157	4	0.816	9	1.344	1
S5	1.184	3	0.929	4	1.274	2
S6	1.212	2	1.000	1	1.212	5
S7	1.246	1	1.000	1	1.246	3
S8	1.058	8	0.948	3	1.116	11
S9	1.150	6	1.000	1	1.150	9
S10	1.184	3	1.000	1	1.184	6
S11	1.033	9	0.846	8	1.221	4
S12	0.900	11	0.879	7	1.024	12
S13	0.880	12	0.895	6	0.983	13
S14	0.850	13	0.999	2	0.851	15
S15	0.734	14	0.646	10	1.136	10
Geometric mean	**1.041**		**0.923**		**1.128**	
Total geometric mean	**0.918**		**0.880**		**1.041**	
Test of significance	p-value	0.017*	p-value	0.044*	p-value	0.130

Note: (1) TR/TC denotes "total revenue" divided by "total cost".

(2) Paired difference experiments are used to test for the same mean between two groups.

(3) "*" means significant at the 5% level of significance.

of about 4.1%, the former public firm incurred losses with total costs exceeding total revenues by 19% on average. In contrast to only 3 out of 15 stations that made profits before privatization, 10 out of 15 stations operated at a profit following privatization. A ranking of pre-privatization performance is very different from a ranking of post-privatization performance across the whole sample of stations. With regard to the decomposition of the “return to the dollar”, the results show that the two firms as a whole suffered from low levels of efficiency (88%), and the SOE with a technical efficiency score averaging 84.2% lagged behind the POE, which had a technical efficiency average of 92.3%. However, as the figures in the allocative efficiency columns indicate, perhaps in an attempt to cover the inefficiency-induced losses, both the SOE and POE adopted distorting relative output prices with respect to inputs prices as an expedient; with the distorting being more pronounced in the POE than in the SOE.

The non-parametric technique reveals that both components of “return to the dollar”, TE and AE, increased immediately following privatization. The decomposition of the “return to the dollar” helps to guide the search for an explanation for the measured profit margin change. In this case, the decomposition indicates that this increase in profit margin appeared to be mostly attributed to allocative progress rather than to improvement of technical efficiency. This will be discussed later. However, the statistical tests show a statistically significant increase both in profit margin, with a p-value of 0.017, and TE with a p-value of 0.044, while there is an insignificant increase in AE with a p-value of 0.130.

The average efficiency scores associated with each of the three station types, i.e., northern (N) region, central (C) region, and southern (S) region before and after privatization are shown in Table 5.3, along with averages for the entire group of 15 stations. More specific origins of these performance changes can be seen in the following station type breakdowns.

Table 5.3 Decomposition of "Return to Dollar" by station type

Station type	TR/TC	Technical	Allocative
TMTC (2000)			
N	**0.870**	**0.852**	**1.021**
C	0.805	0.835	0.964
S	0.734	0.833	0.882
All	0.810	0.842	0.961
GGBC (2002)			
N	**1.139**	**0.957**	**1.190**
C	1.129	0.982	1.150
S	0.874	0.844	1.035
All	1.041	0.923	1.128
Change (2000-2002)			
N	**1.309**	**1.123**	**1.166**
C	1.402	1.176	1.193
S	1.191	1.013	1.173
All	1.285	1.096	1.174

As can be noted in the upper part of Table 5.3, the stations of the northern region dominated the other station types in all three efficiency dimensions. Before privatization, for example, the stations of the northern region incurred losses with total costs exceeding total revenues by 13.0% on the average, less than the 14.8% technical inefficiency, and with an allocative efficiency of 1.021. This may imply the ability to distort output prices at a higher rate (2.1%) than input prices. In the central region group, on the other hand, the average profit margin was about negative 19.5%, with technical and allocative components of 0.835 and 0.964, respectively. As for the stations of the southern region, they averaged 26.6% negative profit margins, a less than 16.7% technical inefficiency, and a less than 11.8% allocative inefficiency.

The post-privatization patterns of performance, as shown in the middle part of Table 5.3, are similar to those of pre-privatization, though with relatively higher performance scores. The stations of the northern region, for example, exhibit a significant increase in profit margin, due to both an increase in the technical and allocative components.

Noteworthy is that the technical efficiency goes from 0.852 to 0.957 between the two organization types. This implies that the stations of the northern region convert their input resources into output more efficiently following privatization. As for allocative efficiency which goes from 1.021 to 1.190, this may imply the ability to distort output prices at a higher rate (16.9 %) than input prices.

The stations of the central region experienced a similar increase in profit margin, due more to an allocative component than to a technical component, and this former figure rose from 0.964 to 1.150 between the years, while the latter also increased from 0.835 to 0.982. The southern region group also displays a similar pattern, however, as the profit margin change indicates that KKTC still incurred a loss of 12.6%. Consequently, one might say that although the stations of the southern region, in terms of converting input resources into output, made correct decisions after privatization, they were still operating less well than the other two regions' units, due probably to the competitive pressure in this region being relatively small. Furthermore, the change in AE was bigger than TE for each station type, as portrayed in the lower part of Table 5.3, thereby confirming that the increase in profit margin came mostly from progress in AE rather than from improvement in TE.

There is another interesting phenomenon relating to the scale of individual bus stations. Figures 5.2, 5.3, and 5.4 depict the inverted U-shaped relationship between the "return to the dollar", technical efficiency, and allocative efficiency for all the sample stations against fleet size, respectively. As can be observed, the results of the three measures suggest that stations of approximately 40-70 vehicles are of optimal size. This is consistent with Cho and Fan's (2003) finding that these stations satisfy constant returns to scale of inputs and output.

In summary, depending on the results of Tables 5.3, and previous discussions, it is found that both TE and AE contribute to the growth of profit margin, with AE playing a more important role than TE.

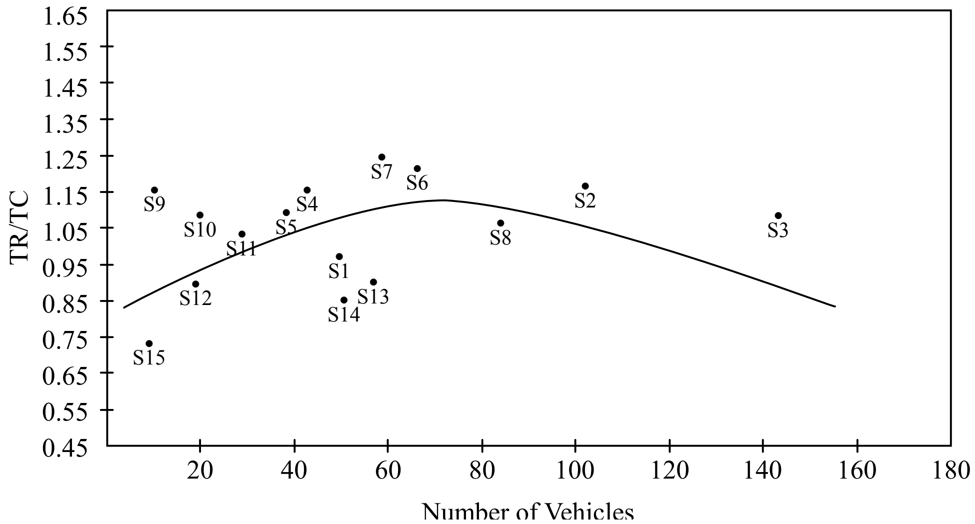

Figure 5.2 TR/TC rating versus number of vehicles (KKTC, 2002)

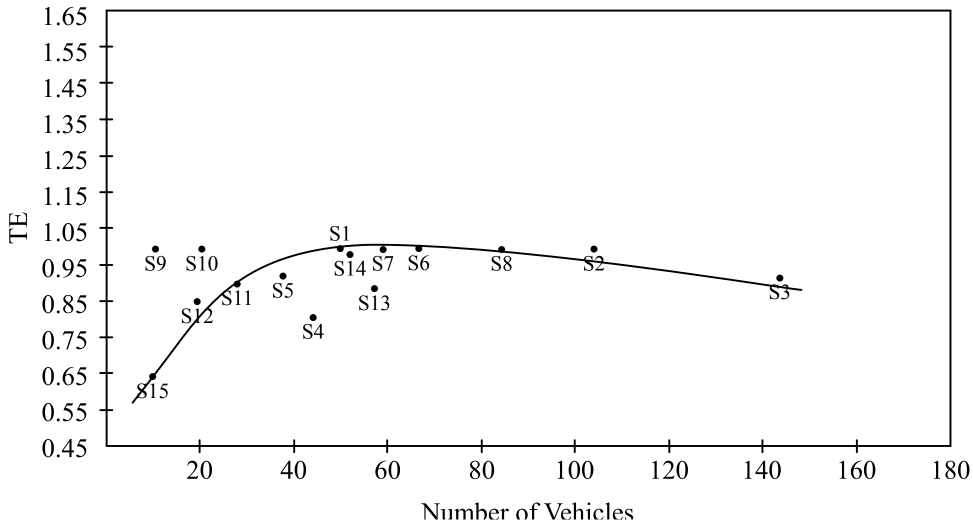

Figure 5.3 Technical efficiency rating versus number of vehicles (KKTC, 2002)

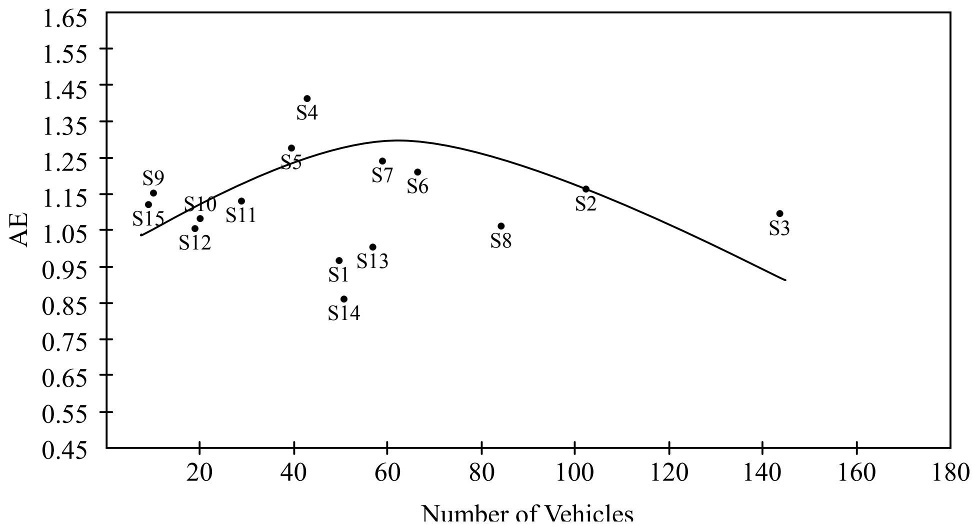

Figure 5.4 Allocative efficiency rating versus number of vehicles (KKTC, 2002)

5.5 Conclusions

Using station-level data of TMTC and KKTC for the years 2000 and 2002, respectively, this study applies a hyperbolic graph efficiency approach to test for "return to the dollar" and the technical and allocative efficiencies of service provided in 15 stations of the firms before and after privatization. Moreover, this study has demonstrated how performance, with respect to the geographical characteristics of the area in which bus stations operate, varies by region.

Whereas the POE has average profit margins of about 4.1%, the former SOE incurred losses with total costs exceeding total revenues by 19% on average. However, given the absence of market information on prices, an allocative efficiency index was employed to measure price distortions using data on observed costs and revenues. Perhaps in an attempt to cover the inefficiency-induced losses, both SOE and POE apparently resorted to distorting relative output prices with respect to input prices; the distortion being more pronounced in POE than in its counterpart. In other words, there was a substantial upgrade in "return to the dollar" for the entire sample of stations after privatization. The decomposition of the "return to the dollar" indicates that this increase in profit margin was mostly due to allocative progress rather than to an improvement in technical efficiency. On the other hand, the aforementioned results are also confirmed by the statistical test which shows a statistically significant increase in TE, simultaneous with an insignificant increase in AE. This suggests that the KKTC converted its input resource into outputs more effectively than its predecessor, while its ability to distort relative output prices with respect to input prices remained constant. The main reason for the latter is that although the cost savings of KKTC, such as reduced pay and wages, appear to have come about through performance improvement, the average fare rate has also fallen as a result of competitive pressure. The decrease both in input and output prices resulting from this, resulted in an unchanged AE following privatization. Furthermore, the changes in the three measures among three different station types were also analyzed and demonstrated a consistent origin of these changes in profit margins. The stations of the northern region virtually dominated the other station types in all three efficiency dimensions. In a final analysis, the inverted U-shaped relationship between the “return to the dollar”, TE, and AE for all the sample stations against fleet size suggests that stations of approximately 40-70 vehicles are of optimal size.

CHAPTER 6

The Case Study 2

─ Measuring the Risk-Adjusted Efficiency of Taiwan Motor Transport Company Before and After Privatization

6.1 Introduction

In the theory of production it is common to assume that outputs are strongly disposable. Classical DEA models, as described e.g., in Charnes et al. (1994), rely on the assumption that inputs have to be minimized and outputs have to be maximized. However, it was mentioned already in the seminal work of Koopmans (1951) that production may also generate undesirable outputs like smoke pollution or waste.

This study intends to employ a directional distance function that incorporates both desirable and undesirable outputs to measure the impact of Taiwan Motor Transport Company's (TMTC's) privatization on its station-level efficiency changes. The directional distance function allows us to consider both the desirable production output, "goods", and the undesirable production output, "bads", in order to measure the linkage between "goods" and "bads" and to assess the level of production inefficiency that gives rise to opportunities in improving efficiency and overall performance simultaneously.

By introducing entrepreneurship and related productivity benefits into bus operations such as downsizing, reducing cost bases, empowering operation management (as will be seen below), the decreasing rate of desirable output (here referred to as vehicle-kilometers) was small in proportion to those of various inputs in the new owner (Kuo Kuang Motor Transport Company, KKTC). This may reveal that efficiency improved following privatization. While evaluating the performance of bus operators, however, transport risks as either internalities or externalities imposed by bus operators upon both users and non-users of the particular mode concerned are needed to be considered simultaneously as undesirable outputs, so as to calculate the overall risk-adjusted efficiency (See e.g., Mester 1996; Chang 1999). Otherwise, the true measure of efficiency could be overestimated or underestimated.

6.2 Model formulation

In this section the model used is explicitly set up to evaluate production in efficiency, and the approach applied is based on the frontier production function. Färe et al. (1989) were the first to apply classic output-oriented DEA analysis to check for production congestion using radial efficiency measures for equiproportional increases of desirable and undesirable outputs. However, the symmetric treatment of outputs in terms of their disposability characteristics looses its justification if one or some of the outputs produced are undesirable goods (2002).

Following this approach, Färe et al. (1998) took a step forward by treating desirable and undesirable outputs asymmetrically. These authors define measures that allow desirable and undesirable production to vary by the same proportion, but desirable outputs are proportionally increased while undesirable ones are simultaneously decreased. The essence of the method is to compute the opportunity cost of transforming the production process from one where all outputs are strongly disposable to one which is characterized by a weak disposability of undesirable outputs.

The goal of this study is to assess the undesirable by-product performance of a set of decision making units (here, DMU refers to stations) by grading their ability to produce the largest equiproportional increase in desirable output and decrease in the undesirable output. Such an evaluation is done through a comparative technique known as DEA which enables the analyst to determine the success of a station in attaining the objective.

This approach establishes a relationship between outputs, U, and inputs, X. Given a vector of inputs, X, the production correspondence is defined as,

$$P(X) = \{U/U \text{ can be produced by } X\} \tag{6.1}$$

If the output vector U may be partitioned into goods and bads, $U = (y,b)$, then the directional distance function increases the good output and decreases the bad (Boyd et al. 2001). The directional output distance function is defined as

$$D_0(x, y, b, g) = \sup\{\beta : ((y,b) + \beta \cdot g) \in P(X)\} \tag{6.2}$$

Figure 6.1 illustrates the directional distance function. The output set is denoted by $P(X)$, the good output by y, and the bad by b. The inequality $Z \cdot Y \geq y_0$ allows for feasible vertical extensions south of the poly tope, reflecting weak disposability of the undesirable outputs. The weak output set is the region OFBCDE. The inequality $Z \cdot B \geq b_0$ allows for a strong disposability of undesirable outputs, so that in Figure 6.1 the strong output set is the region OABCDE. The region OABF represents production possibilities that are feasible under strong disposability of all outputs, but not feasible under weak disposability of undesirable outputs.

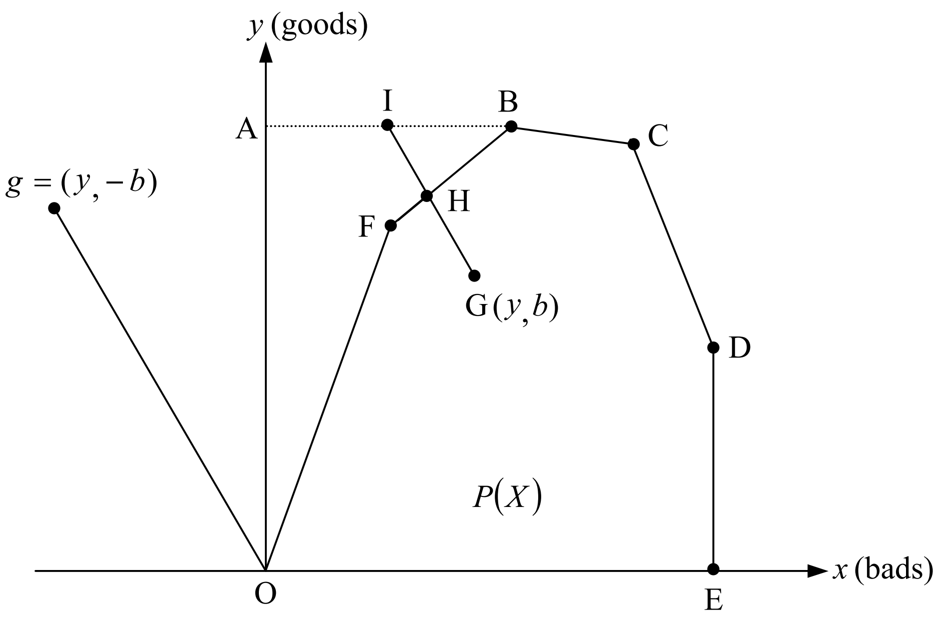

Figure 6.1 Directional Distance Function for Desirable and Undesirable Output Performance

The directional output distance function takes (y,b) in the g direction and places it on the boundary at H or I, depending on whether the technology exhibits free or weak disposal of bad output. The directional distance function under weak disposability, where $g=(y,-b)$, can be estimated from the following linear programming problem:

$$\max_{\theta\geq 0, z\geq 0} \theta \tag{6.3}$$

subject to

$$z \cdot Y \geq (1+\theta)\, y_0 \tag{6.4}$$

$$z \cdot B = (1-\theta)\, b_0 \tag{6.5}$$

$$z \cdot X \leq x_0 \tag{6.6}$$

The program defines the production frontier using the observed combinations of inputs and outputs (X,Y,B) to evaluate inefficiencies of other individual stations (x_0, y_0, b_0), based on the frontier.

6.3 The data

The TMTC station-level data in the period of 2000 and KKTC data for 2002 are used in this study. For each DMU (station) in the sample, four traditional inputs are used for the assessment of efficiency, which are measured in physical units: (1) number of buses in the active fleet (x_1), (2) number of employees (x_2), (3) liters of fuel consumed (x_3), and (4) kilometers of network length (x_4). The single (desirable) output measure is vehicle-kms (y).

Two types of risk indicators are introduced together as the measure of the undesirable outputs. These two indicators are selected to account for the safety quality and riskiness of a station's output. The first one is the amount of accident compensation, including monetary compensation for the fatalities and victims, cost of medical treatment for persons involved in accidents, repair of property damage, costs for legal and court procedures, and others. The second risk measure is the accident liability insurance which is regarded as a provision for risk insurance and is taken here as an output since it is in the form of legal insurance to cover risks that bus or road users might be exposed to if these insurances were not made.

In the interest of analysis these two risk indicators are combined into a single undesirable output measure, and termed as accident and insurance costs (b). A further series, differences in service area population of each station, is added to these measures as an environmental (input) variable to reflect the differences in potential demand impacting on intercity service outputs, but outside of the control of the station management. The intention is to prevent DMUs in remote areas from being disadvantaged in an assessment of relative efficiency over time. The imposed constraint to reflect the above environmental impact can be defined as $Z \cdot E \leq e_0$, where E denotes the observed matrix of the environmental variable.

The whole sample therefore consists of the 15 stations (denoted by S1~S15) of both TMTC and KKTC, along with two years of input and output data (2000 and 2002). All these related data are used to calculate the comparison of the before and after effects of privatization on efficiency. A preliminary examination of summary data before and after privatization reveals the operating changes that have been instituted at TMTC and KKTC, as well as the markets' response to their service offers (Table 6.1). In terms of resources, the KKTC has cut the number of employees by 40%, the number of vehicles by 36%, the liters of fuel used by 24%, and the network length by 22% as compared to TMTC over the study period. Regions on average had a population of 1,467,232 with a standard deviation of 1,232,266 in 2002. Although the number of service area population has slightly increased by 1.0%, the amount of desirable outputs (vehicle-kilometers) has decreased by 12% and undesirable outputs (accident and insurance costs) decreased by 24%, respectively.

Table 6.1 Data Summary for TMTC and GGBC Station

	Inputs				Desirable output	Undesirable output	Environmental variable
	Fleet (vehicles)	Employees (persons)	Fuel (103 liters)	Network length (km)	Vehicle-kilometers (103)	Accident and Insurance costs (103 NT$)	Service Area Population (103 persons)
TMTC (2000)							
Max	169.0	436.0	10,246.9	4,492.1	24,358.0	7,037.3	4,977.4
Min	24.0	47.0	757.7	508.3	2,197.8	341.6	245.3
Mean	83.5	199.3	3,566.5	1,431.9	8,879.0	2,233.8	1,451.5
Std	40.4	107.9	2,447.7	1,067.3	5,813.3	1,891.6	1,221.5
GGBC (2002)							
Max	142.0	318.0	8,144.8	4,449.9	23,794.9	8,317.5	5,020.4
Min	14.0	33.0	493.5	335.5	1,664.9	257.2	244.0
Mean	53.6	112.1	2,696.4	1,111.1	7,563.5	1,694.9	1,467.2
Std	36.8	80.6	2,068.9	1,032.8	5,742.1	2,046.6	1,232.3
Percent Change of Mean	**-35.8**	**-43.8**	**-24.4**	**-22.4**	**-14.8**	**-24.1**	**+1.1**

6.4 Results and discussions

The results of a comparison of the directional distance function and standard DEA model to estimate efficiencies of TMTC before and after privatization are set out in Table 6.2. Note that all the efficient scores should be larger than or equal to 1.0 and that a lower score indicates a more efficient status. However, the efficiency level can be increased in order for the station to achieve a best practice level. An efficiency score of 1 means that the firm is efficient (or equivalent on the frontier).

Looking at the first column, the performance of a station is evaluated on the basis of its ability to expand transit service production with given inputs, regardless of what happens to the risk exposure. The standard efficiency indices diverge from 1.000 to 1.465 with a mean level of 1.195. The results are very different when station performance is judged on the basis of the ability to increase outputs and reduce risk simultaneously.

Table 6.2 Comparison of Directional Distance Function and Standard DEA Model to Estimate Efficiencies of the TMTC before and after Privatization

Station	Standard DEA Model with Envirnmental variable		Dorectional Distnace function	
	Rate	Rank	Rate	Rank
TMTC (2000)				
S1	1.113	10	1.099	9
S2	1.000	13	1.000	13
S3	1.000	13	1.000	13
S4	1.000	13	1.000	13
S5	1.293	6	1.284	3
S6	1.465	1	1.292	2
S7	1.188	8	1.080	11
S8	1.300	5	1.102	8
S9	1.343	2	1.164	6
S10	1.026	12	1.019	12
S11	1.186	9	1.155	7
S12	1.339	3	1.224	4
S13	1.308	4	1.302	1
S14	1.270	7	1.223	5
S15	1.089	11	1.085	10
Average Efficiency	**1.195**		**1.135**	
GGBC (2002)				
S1	1.156	3	1.120	2
S2	1.000	6	1.000	5
S3	1.059	4	1.000	5
S4	1.000	6	1.000	5
S5	1.169	2	1.112	3
S6	1.000	6	1.000	5
S7	1.000	6	1.000	5
S8	1.000	6	1.000	5
S9	1.000	6	1.000	5
S10	1.000	6	1.000	5
S11	1.000	6	1.000	5
S12	1.000	6	1.000	5
S13	1.000	6	1.000	5
S14	1.293	1	1.121	1
S15	1.022	5	1.002	4
Average Efficiency	**1.047**		**1.024**	
Total Average Efficiency	**1.121**		**1.079**	

Column 4 reports the efficiency scores obtained from the directional distance function. This is a stringent standard, and by this criterion the efficiency indices range from a low of 1.000 to 1.302 with a mean level of 1.135. Therefore, a general feature of interest is that efficiency levels for many of the TMTC and KKTC stations appear to be higher under the standard model compared to those under the directional distance function. This may suggest that the stations in the sample are less efficient relative to the relaxed standard than to the more stringent standard. This is due to the incorporation of transport risks as outputs, and also because of the assumption of weak disposability of undesirable outputs which enables the technology to envelop the data more closely.

It is worth noting that a ranking of station performance by a standard model which ignores risk exposures is very much different from a ranking of station performance by a directional distance function which acknowledges risk exposures. This confirms the finding in Fare et al (1989) that failure to credit stations for risk reduction can severely distort the ranking of station performance.

Based on the results derived from a directional distance function, this study now focuses on the evaluation of the risk-adjusted efficiency changes at the station-level of TMTC before and after privatization. As can be seen from the third column of Table 6.2, there are differences in the mean efficiency score between the pre- and post- privatization periods, as POE is found to be superior to its predecessor. The overall mean efficiency index for TMTC computed across the stations, is 1.135, however, corresponding figures for the KKTC as a whole are 1.024. In contrast to only 3 out of 15 stations operating efficiently before privatization, 11 out of 15 stations are deemed as efficient following privatization. The above comparison of both the average efficiency scores and the numbers of efficient units before and after TMTC's privatization provides empirical evidence that POE's operation outperformed the previous SOE's operation. On the whole, the above findings indicate that TMTC's privatization has produced a clear improvement in efficiency enhancement and as such may be considered to be a source of cost reduction.

6.5 Conclusions

The purpose of this article is to apply the directional distance function which incorporates both desirable and undesirable outputs to examine the effects of privatization on TMTC's efficiency changes. This method allows desirable and undesirable production to vary by the same proportion, but desirable outputs are proportionally increased while undesirable ones are simultaneously decreased. Transport risks as undesirable outputs are, for the first time, taken into account to measure the overall risk-adjusted efficiency before and after privatization.

As regards mean efficiency score and ranking order, the results of the comparison between the standard DEA model and the directional distance function implies that the latter appears to be more suited to this empirical study. The empirical findings demonstrate that, in terms of both the number of efficient units and the average efficiency scores, TMTC's privatization has had a noticeable impact on KKTC's efficiency enhancement and as such may be considered to be a source of cost reduction.

CHAPTER 7

The Case Study 3

─ The Joint Determination of Efficiency in Multi-Mode Bus Transit

7.1 Introduction

Improving performance has been widely held to be one of the principal objectives in most transportation organizations. Hence, it is an appropriate way to measure and compare performance with peer groups, with particular reference to the efficient use of resources. As mentioned in Section 1.1 of Chapter 1, however, some transportation organizations may engage in various activities (services) simultaneously, a problem then arises with respect to how the resource can be assigned in an equitable or optimal way to the various activities.

On the other hand, why comprehensive studies on productivity, efficiency, and quality of urban transportation systems need to be capable of handling each mode separately can easily be highlighted by focusing on the important technological and operational differences between the various modes currently in use within urban areas. Also, there is currently, at least, a vast disparity between the levels of utilization of the various urban travel modes－a disparity that is frequently at the center of inefficiency of major system components. All these three factors therefore call for a separate accounting system that will permit the analyst to discover, understand, and illuminate accurately the situation at any given moment and the reasons behind any overall system rating (Tomazins, 1975).

A number of studies have been presented recently, both from a practical organizational standpoint and from a costs research perspective, to deal with this problem (see for example, Golany et al. 1993; Golany and Tamir 1995; Beasley 1995, 2003; Mar Molinero 1996;

Tanassoulis 1996, 1998; Fare et al. 1997; Mar Molinero and Tsai 1997; Tsai and Mar Molinero 1998, 2002; Cook et al. 1999; Cook et al. 2000; Fare and Grosskopf 2002). Among them, the multiactivity DEA model, a novel refinement of the conventional DEA approaches, for the joint determination of efficiencies in the DEA context, was proposed by Beasley (1995) and subsequently revised by Mar Molinero (1996) and Tasi and Mar Molinero (1998, 2002). Specifically, the multiactivity model is used for evaluating efficiencies of organizations that engage in several activities simultaneously. DMUs in this situation may have some inputs and outputs among all the activities, and in doing so, estimate the efficiency with which a given organization carries out each activity.

This study intends to apply the multiactivity model to explore the efficiency of individual services within different but highly homogeneous multimode transit firms in Taiwan. There are three reasons for this. First, the multiactivity model was designed, in particular, to estimate the efficiency achieved by organizations which face several production functions using shared inputs. Second, to the present author's knowledge, few DEA studies relating to multimode transit agencies deal with the shared input problem in a proper way. For example, Viton (1997, 1998) analyzed the efficiency of U.S. multimode bus transit systems operating conventional motor-bus (MB) and demand-responsive (DR) services using DEA. However, the allocation problems of the system costs data appear to have been ignored.

Third, in the present study of the 60 bus companies in Taiwan, 24 of them, operated both highway bus services (HB) and urban bus services (UB) in 2001. Due to dissimilarities in operation characteristics (e.g., headway, frequency, vehicle capacity, load factor, cycle time, and others), which imply different production technologies between these two services, they construct different production functions themselves. Moreover, because of some input resources imposed on the multimode transit firm such as technical labors are devoted to both types of activities (services), they need to decide how to allocate across different

DMUs for the joint (simultaneous) determination of the efficiencies of both services, respectively.

In applying DEA to bus firms, one requires the input and output measures for each service to be specified. The conventional DEA model evaluates the efficiency with which a DMU transforms inputs into outputs. It assumes that DMU is equally efficient in all its activities. However, there are cases in which a DMU faces several production functions. This happens when a DMU is engaged in several activities simultaneously. For example, a transit firm may operate both highway bus services and urban bus services. A transit firm which is efficient at HB may not be efficient in UB, and hence the evaluation of the efficiency of a firm which faces two production functions using shared inputs needs to be solved. As indicated by Diez-ticio and Mancebon (2002), this method was proposed with the object of providing a solution to a weakness in the conventional DEA model, due to its incapacity to evaluate the efficiency of firms which carry out various activities whilst sharing common resource. The main problem is that what is by nature heterogeneous is treated in a homogenous manner, which could lead to a significant degree of distortion in the interpretation of the results. However, how can one determines how efficient each service is at each of its two basic functions, highway bus services and urban bus services?

The approach used in this study is outlined to determine highway bus services and urban bus services' efficiencies. Ideally, the response in such situation would be to design a method for estimating efficiency that is capable of objectively assigning the shared variables to the different activities and that would allow for the independent treatment of each one of them. This method needs to decide which input/output measures are associated with a firm's highway bus services and which are associated with a firm's urban bus services. With regard to output measures, there would probably be a fairly general agreement that vehicle-kms are associated with highway bus service and frequencies of service are associated with urban bus services. However, a problem arises with respect to apportioning input measure to highway buses and/or urban buses. There is probably a fair general agreement that highway bus drivers, fuel, vehicles, and network length are input measures associated with highway buses, while urban bus drivers, fuel, vehicles, and network length are input measures associated with urban buses. Technical staff is composed mainly of technical support for both services. The staff provides both highway bus service and urban bus service, but how much staff supports each service? This question determines how much technical staff associated with highway bus and how much associated with urban bus can be solved by keeping with the spirit of DEA.

7.2 Model formulation

In this section the model used to evaluate multiactivity production inefficiency is set up. As mentioned in the previous section, the approach is based on the frontier production function approach, which explicitly recognizes that some entities (bus firms in this case) are more efficient than others in production. This approach establishes a relationship between outputs, y, and inputs, x. Given a vector of inputs, x, the production correspondence is defined as $p(x) = \{y / y$ can be produced by $x\}$. A revised schematic of the production process for a particular firm is given in Figure 7.1.

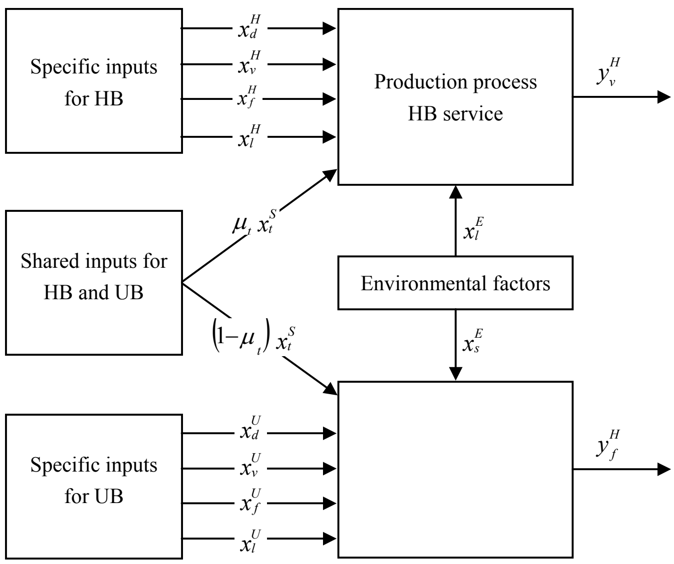

Figure 7.1 Performance dimensions of Multi-mode Transit System

The multiactivity DEA model revised by Mar Molinero (1996) can be applied to the determination of HB and UB efficiency at a set of transit firms in Taiwan. For a DMU k, $y^H_{q,k}(q=1...,\mathrm{Q})$ output, which is solely associated with HB, $x^H_{i,k}(i=1...,\mathrm{M})$ are inputs associated solely with HB, $y^U_{r,k}(r=1...,\mathrm{R})$ are outputs solely associated with UB, $x^U_{i,k}$ are inputs associated solely with UB, but $x^S_{t,k}$ is an input associated in part with HB and in part with UB. Terms $x^E_{\ell,k}$ and $x^E_{s,k}$ are environmental factors associated with HB and with UB, respectively

$$\mathrm{Min}\,\theta = w^H \cdot \theta^{\mathrm{H}}_{\mathrm{k}} + w^U \cdot \theta^U_{\mathrm{k}} \tag{7.1}$$

Highway bus service process technology

$$\sum_{j=1}^{n} \alpha^H_j x^H_{i,j} \le \theta^H_k x^H_{i,k},\ i=1,\cdots,M \tag{7.2}$$

$$\sum_{j=1}^{n} \alpha^H_j y^H_{q,j} \ge y^H_{q,k},\ q=1,\cdots,Q \tag{7.3}$$

Urban bus service process technology

$$\sum_{j=1}^{n} \alpha^U_j x^U_{i,j} \le \theta^U_k x^U_{l,k},\ i=1,\cdots,M \tag{7.4}$$

$$\sum_{j=1}^{n} \alpha^U_j y^U_{r,j} \ge y^U_{r,k},\ r=1,\cdots,R \tag{7.5}$$

Shared input constraint

$$\sum_{j=1}^{n} \mu_t \alpha^H_j x^S_t + \sum_{j=1}^{n} (1-\mu_t)\lambda^U_j x^S_{t,j} \le \theta^H_k \mu_t x^S_{t,k} + \theta^U_k (1-\mu_t) x^S_t \ t=1,\cdots,T \tag{7.6}$$

Environmental factors constraint

$$\sum_{j=1}^{n} \alpha^H_j x^E_{\ell,j} \le x^H_{l,k},\ l=1,\cdots,L \tag{7.7}$$

$$\sum_{j=1}^{n} \alpha^U_j x^E_{s,j} \le x^U_{s,k},\ s=1,\cdots,S \tag{7.8}$$

Here, $x^H_{i,j}$ and $y^H_{q,j}$ are quantities of input i and output q associated only with the UB activity of transit firm j, respectively.

Term $x_{i,j}^{U}$ and $y_{r,j}^{U}$ are quantities of input i and output r associated only with the HB activity of transit firm j, respectively.

Term $x_{t,j}^{S}$ represents quantities of input t associated with HB and UB at transit firm j.

Terms $x_{\ell,j}^{E}$ and $x_{s,j}^{E}$ are quantities of environmental factor l and s associated with HB and UB at transit firm j, respectively.

Terms α^{H}, α^{U} are positive constant associated with the HB production process and UB production process, respectively, while μ_t is the proportion of joint input t associated with HB.

Terms $\theta, \theta_k^{H}, \theta_k^{U}$ are the efficiency scores of HB and UB.

Terms w^{H}, w^{U} are associated with the priorities given to the various activities.

The efficiency model in (7.1) has an input contraction (hence efficiency scores of firms are equal to or smaller than 1) orientation and seeks to estimate the operating efficiencies θ_k^{H} and θ_k^{U} of transit firm k. The assessment is pursued under a constant returns to scale (CRS) assumption while the objective incorporates the cost minimization characteristics of transit production which is consistent with the concept proposed by Talley and Anderson (1981).

7.3 The data

In this study drivers, vehicles, fuel, and network length are included as specific inputs for HB and UB, respectively; technical staff (mechanics) are used as shared input for both HB and UB; and long-haul transportation demand and short-haul transportation demand in Taiwan (Institute of Transportation, MOTC 1999) are included as an environmental variable for HB and UB, respectively. The multiactivity DEA model will then be applied to overcome the shared inputs issue. As for the output measure, vehicle-kms and frequencies of service are selected as a single output for HB and UB, respectively.

The indicator data to be used in the measurement of efficiency in Taiwan's bus transit system is a sample of 24 long established firms located all over the island in 2001. All these DMUs operated both HB and UB. A system which provided only either HB or UB is excluded. All data used in the multiactivity DEA model were obtained from the annual statistical reports published by the National Federation of Bus Passenger Transportation of the Republic of China for 2002.

In the model, inputs x_i^H (such as drivers) are used in HB to produce output y_v^H = VEHKM (vehicle-kilometers). The same method can be applied to urban bus services. Output for urban bus services is given by y_f^U = FREQ (frequencies of service). The production relationship among netput is illustrated in Figure 7.1. The production technology of the multimode bus transit is represented using proxies for inputs and outputs of each of the two modes; that is, four specific inputs, one shared input, one environmental variable and one output. The following set of variables, labeled according to the relationships in Figure 7.1, are used in the empirical application for each mode.

Inputs for highway bus services (x_i^H): the four specific inputs are given by $x_d^H = \text{DRIVER}$ (the number of transportation workers used by this mode in providing the service), $x_v^H = \text{VEHICLE}$ (the fleet sizes, which are taken to be the total number of vehicles operated in maximum service by this mode), $x_f^H = \text{FUEL}$ (the number of liters of fuel by mode), and $x_l^H = \text{NWLTH}$ (network length by mode).

Shared input (x_t^S): this is given by $x_t^S = \text{MEC}$ (the number of mechanics used by the two modes). The allocation of these data is based on the resulting data being derived from the application of the multiactivity DEA model, which is capable of objectively assigning a share to the different activities which will allow for the independent treatment of each of these different activities. This information allows a separation of the shared input, which is necessary for an implementation of the multiactivity DEA model.

Inputs for urban bus service (x_i^U): in the same manner as the highway bus service, the four individual inputs for urban service are given by x_d^U = DRIVER (the amount of transportation workers used by this mode in providing the service), x_v^U = VEHICLE (the fleet sizes, which are taken to be the total number of vehicles operated in maximum service by the mode), x_f^U = FUEL (the number of liters of fuel by the mode) and x_l^U = NWLTH (network length by mode).

Environmental variables (x^E): two environmental factors are considered in this study. There is a set of "environmental factors" including x_ℓ^E =LONG, x_s^E =SHORT (the quantities of long-haul transportation demand and short-haul transportation demand influencing the HB and UB production process respectively). This set describes the situation in which the DMU finds itself. Summary statistics for those variables are reported in Table 7.1.

Table 7.1 Variables and Descriptive Statistics

	Mean	Stdev	Maximum	Minimum
Specific inputs				
Process of HB service				
DRIVE (persons)	158.1	137.0	451.0	8.0
VEHICLE (vehicles)	121.0	107.8	387.0	8.0
FUEL (liters)	3,084,916.9	2,431,013.4	8,154,152.0	281,700.0
NWLTH (kms)	1,248.2	1,134.0	3,765.9	31.4
Process of UB service				
DRIVER (persons)	137.2	175.1	633.0	3.0
VEHICLE (vehcles)	120.3	145.2	557.0	3.0
FUEL (liters)	3,386,796.7	4,857,287.8	16,362,765.0	44,381.0
NWLTH (kms)	248.5	228.9	1,006.5	18.0
Shared inputs				
MEC (persons)	39.6	32.3	117.0	3.0
Outputs				
Process of HB service				
VEHKM (veh-kms)	8,533,146.4	6,956,059.8	25,378,595.3	775,231.7
Process of HB service				
FREQ (frequencies)	790,040.5	1,131,977.4	4,115,662.0	14,540.0
Environmental variables				
LONG (trips)	2,561,627.0	2,362,657.0	8,200,170.0	4,061.0
SHORT (trips)	2,678,656.0	2,718,008.0	7,851,043.0	187,984.0

7.4 Results and discussions

The 24 4-specific input, 1-shared input, 2-environmental variable, and 2-specific output DMUs were used here to test the CCR (Charnes et al., 1978) model and the multiactivity DEA model, and to compare overall efficiency on the real data set. It would be reasonable to compare the rates obtained from the multiactivity DEA model which acknowledges the possible technological differences of the various services performed by transit firms, with those derived from a conventional DEA model which ignores those of technological differences and combines them into one single measurement model.

The results of the comparison are set up in Table 7.2. It is noticeable that, in terms of the number of efficient units, average efficiency score, and ranking order, the multiactivity

Table 7.2 Comparison of the CCR and Multiactivity Models' Efficiency Scores

DMU	CCR Scores		Multiactivity Scores	
	rating	ranking	rating	ranking
Tayou	1.000	1	1.000	1
Fuho	1.000	1	1.000	1
Chunghsing	1.000	1	0.984	3
Chihnan	0.924	4	1.000	1
Kuanghua	1.000	1	0.992	2
Tamshui	1.000	1	1.000	1
Hsinho	1.000	1	0.932	6
Taipei	1.000	1	0.808	11
Sanchung	1.000	1	0.894	7
Capital	1.000	1	0.760	15
Hsintien	1.000	1	0.984	3
Hualien	1.000	1	0.958	5
Taoyuan	1.000	1	0.932	6
Chungli	0.834	7	0.831	10
Hsinchu	1.000	1	0.960	4
Fengyuan	0.963	3	0.832	9
Chuyeh	0.879	6	0.769	14
Taichung	0.897	5	0.664	19
Jenyou	1.000	1	0.791	12
Changhua	1.000	1	0.721	16
Chiayi	0.973	2	0.779	13
Tainan	0.783	8	0.709	18
Kaohsiung	1.000	1	0.715	17
Pingtung	1.000	1	0.837	8
Maximum value	1.000		1.000	
Minimum value	0.783		0.664	
Average efficiency	**0.969**		**0.869**	
Std.dev	0.061		0.113	
Number of efficient firm	17		4	

model is not only very much different, but also much more demanding than those of the CCR model. Commensurate with the observations of Diez-Ticio and Mancebon (2002), this is explained by the fact that the achievement of maximum efficiency in the multiactivity model requires that good productive behavior be demonstrated on the part of the two activities, while with the CCR model it is possible for there to be compensations between the two.

Having considered the function of the transit production and having carried out an efficiency evaluation using the earlier described methods, the resulting overall highway bus and urban bus efficiency scores are displayed in Table 7.3. It is noted that of the 24 bus firms analyzed, only four (those of Tayou, Fuho, Chihnan, and Tamshui; all in the Taipei metropolis) are efficient in the aggregate sense; that is, both in highway bus services and urban bus services. Clearly, firms maybe efficient in one mode only, such as is the case for Kuanghua and Hsinho. If highway bus transit is concentrated on, then eight of the transit firms exhibit productive behavior that is superior to the rest. Regarding urban transit, a maximum level of efficiency is achieved by seven companies, with DMUs that are efficient in each of the two services coinciding in only four cases.

With regards to average efficiency, it is worth noting that this differs distinctly in the two modes, with that of highway bus transit demonstrating a higher average rate of efficiency. This implies that, in terms of providing their observed output using fewer inputs, the highway transit DMUs outperformed their counterparts.

In the interest of analysis, these 24 multimode transit firms are divided into four groups based on the geographical characteristics of the area in which these bus firms operate. Such information would probably help explain some of the differences found in the performance between firms of the different regions; that is, Taipei metropolis (TM) region including eleven firms (from Tayou to Hsintien); northern (N) region including four firms (from Hualien to Hsinchu); central (C) region including five firms (from Fengyuan to Changhua);

and southern (S) region including the rest of the five firms (from Chiayi to Pingtung); as shown in Table 7.3.

Table 7.3 Efficiency Scores of the Mutiactivity DEA Model

DMU	Overall efficiency	Highway bus efficiency	Urban bus efficiency
TM			
Tayou	1.000	1.000	1.000
Fuho	1.000	1.000	1.000
Chunghsing	0.984	1.000	0.967
Chihnan	1.000	1.000	1.000
Kuanghua	0.992	1.000	0.983
Tamshui	1.000	1.000	1.000
Hsinho	0.932	0.864	1.000
Taipei	0.808	0.667	0.948
Sanchung	0.894	0.787	1.000
Capital	0.760	0.756	0.764
Hsintien	0.984	0.970	0.997
Average efficiency	**0.935**	**0.913**	**0.968**
N			
Hualien	0.958	1.000	0.916
Taoyuan	0.932	0.864	1.000
Chungli	0.831	1.000	0.662
Hsinchu	0.960	0.939	0.980
Average efficiency	**0.920**	**0.951**	**0.890**
C			
Fengyuan	0.832	0.845	0.819
Chuyeh	0.769	0.763	0.774
Taichung	0.664	0.772	0.555
Jenyou	0.791	0.945	0.637
Changhua	0.721	0.906	0.535
Average efficiency	**0.755**	**0.846**	**0.664**
S			
Chiayi	0.779	0.864	0.694
Tainan	0.709	0.923	0.495
Kaohsiung	0.715	0.882	0.547
Pingtung	0.837	0.873	0.801
Average efficiency	**0.760**	**0.886**	**0.634**
All			
Maximum value	1.000	1.000	1.000
Minimum value	0.664	0.667	0.495
Average efficiency	**0.869**	**0.901**	**0.836**
Std.dev	0.113	0.098	0.182

Note: **TM** stands for Taipei Metropolis

N stands for northem region

C stands for central region

S stands for southem region

As can be noted, the estimated efficiencies range from a low of about 0.667 to 1, with a small standard deviation of 0.098 in the highway transit. It should be pointed out that despite a declining trend in transit demand all over Taiwan in the early 1990's, highway transit type of service, as a consequence of the greater transportation demand to be satisfied, remains an important transportation mode. The priority given by transit firms to this could be one of the reasons that explains the small difference among efficiencies in the various regions. As for urban transit there is a large discrepancy between the maximum (1.000) and minimum (0.495) efficiencies, along with a standard deviation (0.182) being nearly twice that of highway transit. The estimated average efficiency is quite high (0.968) in the Taipei metropolis compared to other regions, partly because urban transit is the main transportation mode in this region. This mode is relatively less important among the others regions, especially in the central and southern regions, and hence results in a much lower average efficiency with 0.664 and 0.634, respectively.

7.5 Conclusions

This empirical study attempts to determine the efficiency of Taiwanese multimode transit firms which jointly carry out highway bus services and urban bus services with non-identical technologies and used shared inputs. In this regard, the multiactivity model applied in the present paper shows itself to be an especially useful instrument in performing this task. The results of the comparison between the CCR and the multiactivity models indicate that the latter is not only very much different, but also much more demanding than the former, in terms of the number of efficient firms, average efficiency score, and ranking order. The empirical analysis of the 24 multimode transit firms by way of an investigation of dividing them into four regions reveals the existence of noticeable differences in the performance of the transit firms studied, as indicated by the divergences obtained in the efficiency rates.

CHAPTER 8

The Case Study 4

─ Measuring the Performance of Multimode Bus Transit: A Network DEA Model

8.1 Introduction

Tomazins (1975) indicates that transportation service constitutes a perishable commodity which if not utilized (sold, consumed) at the time and place of its production is lost forever. Thus, the importance of producing this commodity as close as possible to the specifications of its potential user is great. This implies a perfect match of produced services and consumed services is vitally important.

On the other hand, he argued that why comprehensive studies on productivity, efficiency, and quality of urban transportation systems need to be capable of handling each mode separately can easily be highlighted by focusing on the important technological and operational differences between the various modes currently in use within urban areas. Also, there is currently, at least, a vast disparity between the levels of utilization of the various urban travel modes—a disparity that is frequently at the center of inefficiency of major system components. All these three factors therefore call for a separated accounting system that will permit the analyst to discover, understand, and illuminate accurately the situation at any given moment and the reasons behind any overall system rating.

This study presents an approach to include both the unstorable characteristics of transportation service and the technological differences mentioned above within multimode transit firms in efficiency and effectiveness measurement. The proposed network DEA model differs from conventional models in two respects: First, the consumed services occurring concurrently with the produced services are explicitly taken into account, and second, the network model allows a representation of both production and consumption technologies in a unified framework and hence can be used to simultaneously esitimate the cost efficiency, the service effectiveness and the cost effectiveness of multimode transit firms which carry out their services with non-identical technologies and use shared inputs.

Specifically, the proposed network DEA model is applied to production and consumption data for a sample of multimode bus transit firms in Taiwan. Of the 60 bus companies in Taiwan, 24 of them operated both highway bus services (HB) and urban bus services (UB) in 2001. However, one of the main questions that must be addressed when seeking to evaluate the efficiency or effectiveness of a set of decision making units (DMUs) is to ensure that the peer groups being evaluated are made up of highly homogeneous units. This is required because, as Tomkins and Green (1988) indicated, any type of specialization on the part of one productive unit will automatically make it appear efficient, given that none of the others will compete with it in this activity. Further, due to the dissimilarity in technological and operating characteristics between these two kinds of services, they are required to be separated to evaluate their efficiency or effectiveness respectively.

On the other hand, according to the Highway Act (2002), the Highway Bureau and the local Traffic Bureau are responsible for monitoring the operating performance of the bus firms, especially those receiving operating subsidies from central and local governments. The governments are interested in how efficient the produced service is being used, while the operator is particularly interested in how effective they are producing the service. The goal of the transit firm is a high level of cost minimization and a maximum consumption utilization, and therefore it is important that transit performance measures take these two aspects into consideration.

8.2 The framework of performance evaluation

Drawing upon the finding of Fielding (1987), Hooper and Hensher (1997) indicated that the cost efficiency of a transit agency represents the manner in which the physical inputs of labor, energy, maintenance materials, capital and overheads are used to produce the physical services (intermediate output) such as frequency of service and vehicle-km. Effectiveness has two essential components:

1. cost effectiveness－the relationship between inputs and consumed services (final output) such as passengers or passenger-kilometer.
2. service effectiveness－the relationship between produced services (intermediate input) and consumed services (final output).

Cost per passenger and the ratio of revenue to the cost of producing service are overall measures. Cost efficiency, service effectiveness, and cost effectiveness are the terms used to describe the three dimensions of transit performance presented in Figure 8.1. However, in addition to efficiency and effectiveness, it is worth noting that relationships also exist between the efficiency and effectiveness criteria.

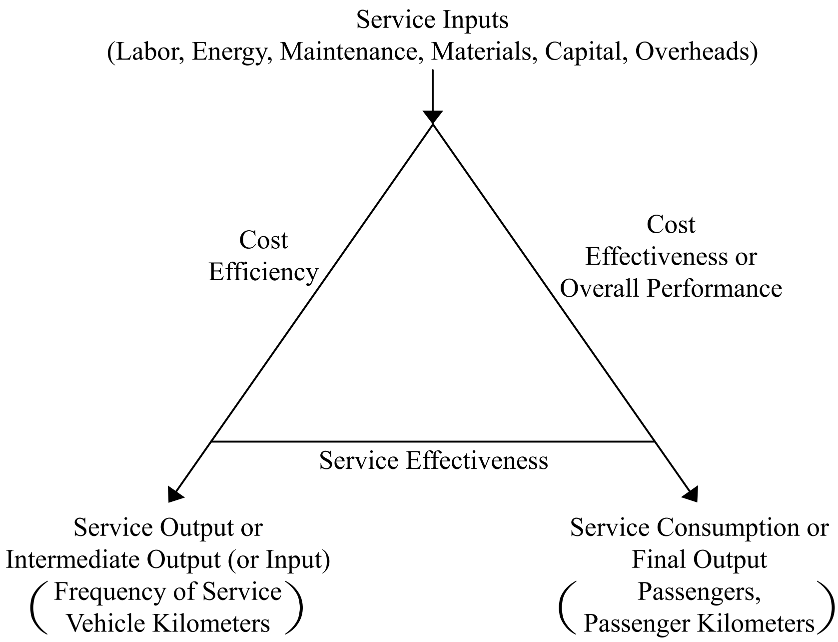

Figure 8.1 Framework for Transit Performance Concepts

For example, it is possible to produce reliable service and deploy it in the right area at the right time, but find that consumers simply choose not to use it (Fielding, 1987). Moreover, the meaning of such measure is obscured by the lack of understanding of how the impacts of efficiency and effectiveness are inter-related. For example, does a poor performance indicate a high level of service, poor management, or inadequate attention to marketing? Answers to such questions require that a measurement structure be established to specify how production and consumption are inter-related.

Individual transit firms are assumed to operate a production process which inputs market conditions, competition and resource levels to generate outputs in the form of final outputs and service sold to customers. This production process has however inter-relationships among production, consumption and environmental factors. That is to say, one must differentiate between the role of the transit operator and that of the local operating environment in determining transit characteristics. From a transit operator's point of view, the concern is with the most efficient utilization of resources available to him in the production of a marketable transit service. Given certain minimum requirement service level constraints from the government, the operator is usually in almost complete control of the way in which he combines available resources to produce the desired service, and to minimize cost. His concern is to maximize the amount of produced service used by customers. There is an important point in transit service production. The efficient provision of a certain transit service is a necessary but not a sufficient condition for obtaining a good service. A system might have excellent management and a high efficient production process, yet it may not be producing the type of output that is desired by the user or by society at large. Specifically, while evaluating transit performance, it is noticeable that while an efficient transit system will produce vehicle-kms at a reasonable cost, these vehicle-kms do not contribute to mobility until they become passenger-kms. The fact that service can not be stored is an important characteristic of a transit system. If the final output is not consumed simultaneously with the intermediate output, it perishes. Since the efficiency and effectiveness are concerned with produced and consumed output respectively (McCrosson, 1978), this unique unstorable characteristic of the transit system allows us to integrate the effectiveness with the efficiency measurement, taking into account that transit inputs relate directly to intermediate outputs, and so to final outputs. In other words, these three performance indicators can be determined simultaneously to imply this unique characteristic. Effectiveness is therefore jointly determined by the transit operator's decision and by the characteristics of the local environment in which the transit service operates. In addition, multimode transit firms are usually engaged in several activities simultaneously, such as highway bus service and urban bus service. These two activities have different boundaries when it comes to production possibility, but some inputs may be shared amongst them. For example, a highway bus service utilizes some inputs, shared or specific ones, in order to generate relevant output/outcome, e.g., vehicle-kms/passenger-kms, while urban bus service concentrates on frequencies of service or passengers using relevant shared or specific inputs. This multiactivity production problem raises the possibility that some inputs may indeed be shared amongst activities, but that other inputs may be specific to given activities. The above discussion leads to the proposition that there exist an overall measurement framework, which is depicted in Figure 8.2.

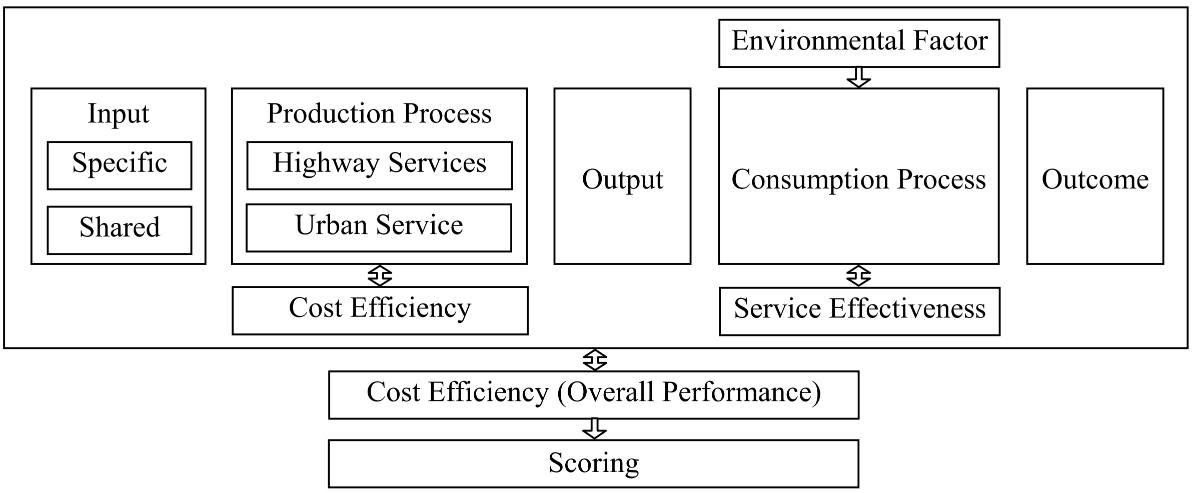

Figure 8.2 Framework of Transit Firm Performance

The multistage production process in Figure 8.2 describes three vital parts of transit firm operations, namely, produced services, consumed services and inputs shared among activities and/or processes. The characteristic point in this framework is to separate outcome from output, so that this study is able to emphasize the dimension of each part that has a close relationship with the overall performance. The innovation introduced in Figure 8.2 concerns the inputs shared among activities and the simultaneous determination of efficiency and effectiveness, which is recognized as a key determinant of the performance of transit firms. On the other hand, key issues of transit firm operations are, the external environmental conditions and the effort made by each transit firm in terms of allocating physical and human resources.

8.3 Model formulation

Methodology for assessing transit performance embraces two concepts: effectiveness and efficiency (US. Department of Transportation, 1978). However, a number of drawbacks to conventional methods for transportation evaluation are related to their inability to deal with these two concepts. (Stopher and Meybury, 1976). Chu *et al.* (1992) provided a mathematical technique based on DEA to analyze the efficiency with which service is produced and the effectiveness with which it is consumed. By using DEA, a single index for efficiency and a single index for effectiveness can be constructed. As mentioned in previous section, the development of transit indicators separating cost efficiency, service effectiveness and cost effectiveness is summed up by Fielding (1987).

The standard DEA model evaluates the efficiency with which a DMU transforms inputs into outputs. It assumes that a DMU is equally efficient in all its activities. However, there are cases in which a DMU faces several production functions. This may happen when a DMU is engaged in several activities simultaneously, for example, transit firms that operate both highway bus services and urban bus services. A transit firm which is efficient at HB service may not be efficient in UB service, thus, different efficiency ratings for different activities should be distinguished. Moreover, produced services can not be stored, and the consumed services occur concurrently with the produced services. Ideally, the response in such situations would be to design a method for estimating performance where the shared inputs can be assigned to different activities and /or different processes, as well as where the intermediate products between the production and consumption process is allowed. Thus, the combination of the production and consumption processes into a single model will be introduced for DMUs which jointly engage in multiple activities and/or multiple processes.

8.3.1 Network production possibility set

The starting point of all above-mentioned proposals is that when one DMU jointly carries out various activities and processes which can not be assumed to be technologically identical, is to separate these activities and processes into different technologies in a network model. The application of the traditional DEA model is to evaluate transit performance which assumes that the DMU is equally efficient in all its activities, and to assess cost efficiency, service effectiveness and cost effectiveness by using three separate DEA models. The main problem is that what is by nature concurrent is treated in a consecutive manner, which could lead to a significant degree of distortion in the interpretation of the results.

In order to solve this problem, this study proposes a modified network DEA model introduced by Fare and Grosskopf (2000), in order to represent a production and consumption process in the transit technology. Consider, for the sake of simplicity, a two-activity transit firm with only two different services which outputs are the intermediate inputs of the consumption process in the model.

Consider a set of $j = \{1,...,n\}$ transit firms which use input quantities $X = (X_{aj}^{PH}, X_{bj}^{PH}, X_{cj}^{PC}, X_{dj}^{PCC}, X_{ej}^{C})$, $a = \{1,...,m_a\}$, $b = \{1,...,m_b\}$, $c = \{1,...,m_c\}$, $d = \{1,...,m_d\}$, $e = \{1,...,m_e\}$ to produce intermediate output quantities $Y^P = (Y_{fj}^{PH}, Y_{gj}^{PU})$, $f = \{1,...,s_f\}$, $g = \{1,...,s_g\}$, and final output quantities $Y^C = (Y_{lj}^{C}, Y_{oj}^{C})$, $l = \{1,...,z_l\}$, $o = \{1,...,z_o\}$, where inputs, which are associated only with HB, will be given the superscript PH. Inputs which are associated only with UB will be given the superscript PU, inputs which contribute to both highway bus service and urban bus service will be given the superscript PC, inputs which are associated only with the consumption process will be given the superscript C, whereas inputs which contribute to both highway bus service and urban bus service as well as the consumption process will be given the superscript PCC. For example, $X_a^{PH} = (x_d^{PH}, x_f^{PH}, x_v^{PH}, x_l^{PH})$ are inputs associated solely with HB, such as drivers, fuel, vehicles and network length, but $X_c^{PC} = (x_t^{PC})$ is an input associated in part with HB and in part with UB, such as mechanics. $Y_f^{PH} = (y_h^{PH})$ representing produced outputs of HB service, such as vehicle-kms, is an output which is solely associated with HB, whereas $Y_g^{PU} = (y_u^{PU})$ are the results of UB service, such as frequencies of service. Y^P has the characteristics of intermediate products which are intermediate to the production system and are consumed by the consumption system together with specific inputs $X_e^C = (x_s^C)$ of the consumption process, such as sales staff deliver to the consumption process. The products of the consumption process, $Y^C = (Y_l^C, Y_o^C)$, which is the final output matrix with outputs Y_l^C and Y_o^C, outputs $Y_l^C = (y_h^C)$ are the result of the consumed HB service, such as passenger-kms, outputs $Y_o^C = (y_u^C)$ are the result of consumed UB service, such as passengers. The network model is depicted in Figure 8.3.

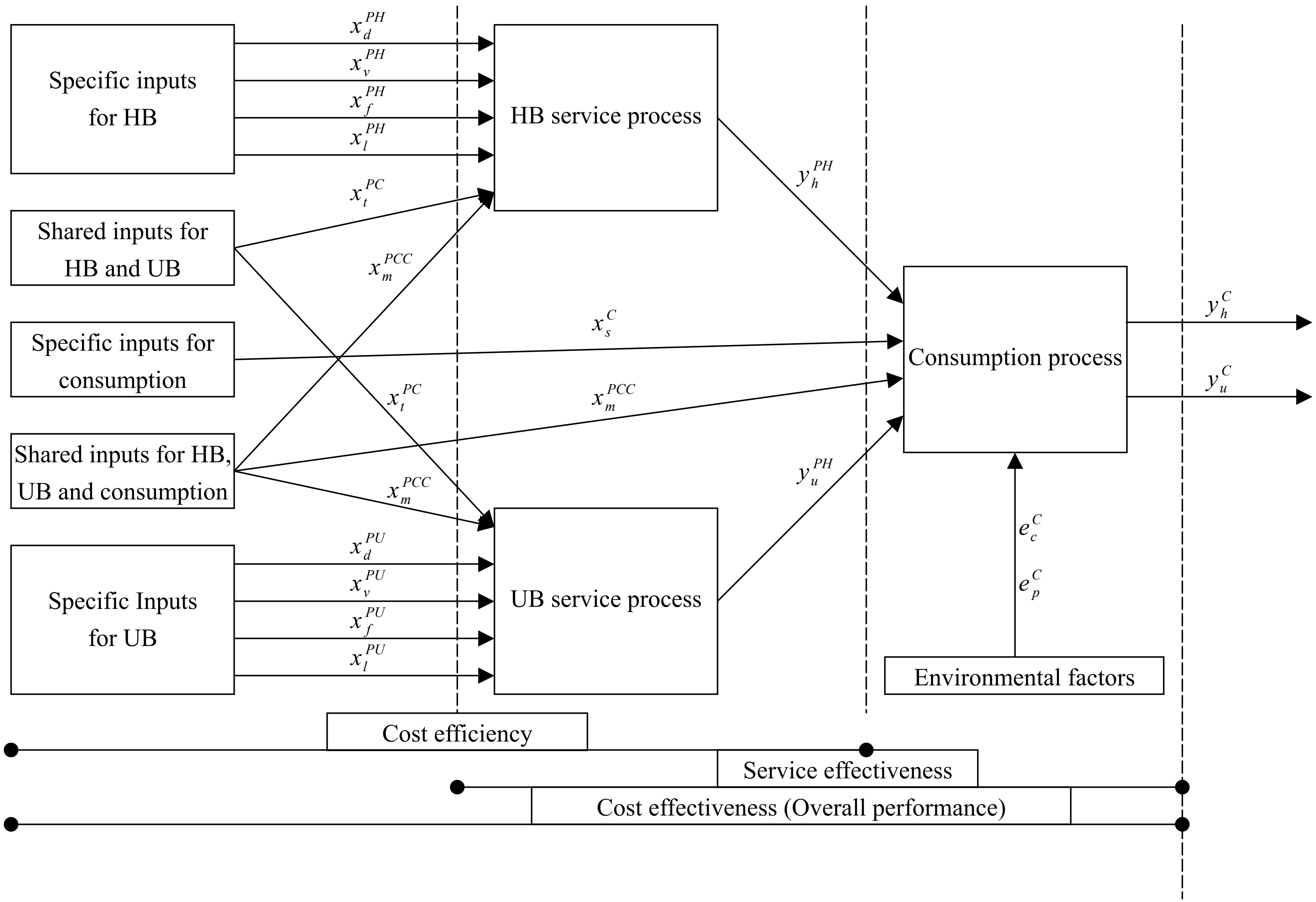

Figure 8.3 Performance Dimensions of Multi-mode Transit System

In the situation where there are inputs associated with both activities or among activity HB, activity UB and the consumption process, then one will assume that these shared inputs can be apportioned between HB and UB, or among activity HB, activity UB and consumption process. In this way, each joint input will contribute to the determination of the cost efficiency of the HB, and of the cost efficiency of the UB in the production process, as well as the determination of the service effectiveness of the consumption process. Assume that the proportion of the shared inputs assigned to each one of the said activities are μ_c and $1-\mu_c$, and the proportion of the shared inputs assigned to each one of the said activities and the consumption process are α_d^1, α_d^2 and $1-\alpha_d^1-\alpha_d^2$. Then the model for the network DMUs will have the HB, UB and consumption process production possibility set A^{PH}, A^{PU}, A^C, defined as follows:

$$A^{PH} = \{(X^I, Y^I) : Y^I \text{ can be produced from } X^I,$$
$$X^I = (X_a^{PH}, \mu_c X_c^{PC}, \alpha_d^1 X_d^{PCC}), \text{ and } Y^I = Y_f^{PH}\},$$

and

$$A^{PU} = \{(X^{II}, Y^{II}) : Y^{II} \text{ can be produced from } X^{II},$$
$$X^{II} = (X_b^{PU}, (1-\mu_c) X_c^{PC}, \alpha_d^2 X_d^{PCC}), \text{ and } Y^{II} = Y_g^{PU}\}.$$

and

$$A^C = \{(X^{III}, Y^{III}) : Y^{III} \text{ can be produced from } X^{III},$$
$$X^{III} = (Y_f^{PH}, Y_g^{PU}, (1-\alpha_d^1-\alpha_d^2) X_d^{PCC}, X_e^C), \text{ and } Y^{III} = Y^C\}.$$

If A^{PH} is the smallest set satisfying the convexity, constant returns to scale, free disposability, and minimum extrapolation postulates (Tsai and Mar Molinero, 2002), subject to the condition that each of the input-output observations $(X^I, Y^I) \in A^{PH}$, then the HB input set $P^H(Y^I)$ for each Y^I can be defined as

$$P^H(Y^I) = \{X^I : (X^I, Y^I) \in A^{PH}\}.$$

Similarly, the UB input set $P^U(Y^{II})$ for each Y^{II} can be defined as

$$P^U(Y^{II}) = \{X^{II} : (X^{II}, Y^{II}) \in A^{PU}\},$$

and the consumption process output set $P^C(X^{III})$ for each X^{III} can be defined as

$$P^C(X^{III}) = \{Y^{III} : (X^{III}, Y^{III}) \in A^C\}.$$

The network model gives some insights into how inputs may be shared by different processes and inter-related effects between different processes. Here, x_{cj}^{PC} can be allocated between the two activities, x_{dj}^{PCC} can be allocated among the two activities and the other process, and the others are pre-assigned to a specific process for each DMU *j*. In this case, the network production possibility set is shown below in (8.1).

$$P(X) = \Bigg\{ (Y^C) : \sum_{j=1}^{n} \lambda_j^H x_{aj}^{PH} \le x_{ak}^{PH}, a = 1, \cdots, m_a,$$

$$\sum_{j=1}^{n} \lambda_j^U x_{bj}^{PU} \le x_{bk}^{PU}, b = 1, \cdots, m_b,$$

$$\sum_{j=1}^{n} \lambda_j^H \mu_c x_{cj}^{PC} \le \mu_c x_{ck}^{PC}, c = 1, \cdots, m_c,$$

$$\sum_{j=1}^{n} \lambda_j^U (1-\mu_c) x_{cj}^{PC} \le (1-\mu_c) x_{ck}^{PC}, c = 1, \cdots, m_c,$$

$$\sum_{j=1}^{n} \lambda_j^H \alpha_d^1 x_{dj}^{PCC} \le \alpha_d^1 x_{dk}^{PCC}, d = 1, \cdots, m_d,$$

$$\sum_{j=1}^{n} \lambda_j^H y_{fj}^{PH} \ge y_{fk}^{PH}, f = 1, \cdots, s_f,$$

$$\sum_{j=1}^{n} \lambda_j^U y_{gj}^{PU} \ge y_{gk}^{PU}, g = 1, \cdots, s_g,$$

$$\sum_{j=1}^{n} \lambda_j^U \alpha_d^2 x_{dj}^{PCC} \le \alpha_d^2 x_{dk}^{PCC}, d = 1, \cdots, m_d,$$

$$\sum_{j=1}^{n} \lambda_j^C (1-\alpha_d^1-\alpha_d^2) x_{dj}^{PCC} \le (1-\alpha_d^1-\alpha_d^2) x_{dk}^{PCC}, d = 1, \cdots, m_d,$$

$$\sum_{j=1}^{n} \lambda_j^C x_{ej}^C \le x_{ek}^C, e = 1, \cdots, m_e,$$

$$\sum_{j=1}^{n} \lambda_{\mathrm{j}}^{\mathrm{C}} y_{fj}^{PH} \le y_{fk}^{PH}, f = 1, \cdots, s_f,$$

$$\sum_{j=1}^{n}\lambda_j^C y_{gj}^{PH} \le y_{gk}^{PH}, g = 1,\cdots,s_g,$$

$$\sum_{j=1}^{n}\lambda_j^C y_{lj}^C \ge y_{lk}^C, l = 1,\cdots,z_l,$$

$$\sum_{j=1}^{n}\lambda_j^C y_{oj}^C \ge y_{ok}^C, o = 1,\cdots,z_o,$$

$$\lambda_j^H \ge 0, \lambda_j^U \ge 0, \lambda_j^C \ge 0, j = 1,\cdots,n\} \quad (8.1)$$

The main difference between the conventional model and the network model is that in this model the allocation of shared input x_{cj}^{PC}, x_{dj}^{PCC} between the two processes is not given a *priori* like the other inputs $x_{aj}^{PH}, x_{bj}^{PU}, x_{ej}^{C}$, and provides a possibility to use the outputs of the production process as intermediate inputs in the consumption process. The conventional model does not provide for such allocation and processes, since it can be viewed as an aggregation of this network model that obscures the subprocess, such as the model constructed for measuring technical efficiency in multimode bus transit by Viton (1997).

8.3.2 Directional distance function

The most general of distance is the directional distance function, which is defined on the output set $P(x)$ by

$$\vec{D}(x, y; g_x, g_y) = \max\{\theta : (y + \theta g_y) \in P(x - \theta g_x)\} \quad (8.2)$$

Standard DEA or Farrell (1957) technical efficiency measures are closely related to the distance function. Shephard's (1970) input and output distance functions, are defined as $D_i(y, x) = \sup\{\alpha : y \in P(x/\alpha)\}$ and $D_o(x, y) = \inf\{\delta : (y/\delta) \in P(x)\}$, respectively. The relation between them is given by $D_o(x, y) = 1/D_i(y, x)$. The output (input) distance function expands (reduces) the outputs (inputs) proportionally as much as is feasible. The reciprocal of the output distance function is known as the Farrell output measure of technical efficiency. The input and output distance functions are special cases of the directional distance function Eq. (8.2).

If the input oriented DEA model is chosen, then the directional distance function $\vec{D}(x,y;x,0)=1-1/D_i(y,x)$. Similarly, if the output oriented DEA is taken, then $\vec{D}(x,y;0,y)=(1/D_o(x,y))-1$.

When all of the three parts as mentioned in section 8.3.1 have different efficiency scores $\theta_k^H,\theta_k^U,\theta_k^C$, this study introduces the three functions $\theta_k^H(X^I,Y^I)$, $\theta_k^U(X^{II},Y^{II})$ and $\theta_k^C(X^{III},Y^{III})$ which will provide a measure of how efficient a firm *k* is at HB, UB and consumption process, respectively. If no input was associated with both HB and UB, or among HB, UB and consumption process, then the overall process doesn't have the characteristics of the consumed services occur concurrently with produced services in the real world. The efficiency score of each part could then be calculated by ignoring all inputs associated with any one of the three parts and by running the model only for each part as follows:

$$\vec{D}(X^I,Y^I)=\theta_k^H(X^I,Y^I)=\max\left\{\theta_k^H:(1-\theta_k^H)X^I\in P^H(Y^I),\theta_k^H\geq 0\right\}$$

$$\vec{D}(X^{II},Y^{II})=\theta_k^U(X^{II},Y^{II})=\max\left\{\theta_k^U:(1-\theta_k^U)X^{II}\in P^H(Y^{II}),\theta_k^U\geq 0\right\}$$

$$\vec{D}(X^{III},Y^{III})=\theta_k^C(X^{III},Y^{III})=\max\left\{\theta_k^C:(1+\theta_k^C)Y^{III}\in P^C(X^{III}),\theta_k^C\geq 0\right\}$$

As for the evaluation framework of the transit firm mentioned above, the evaluation concepts include the production and consumption processes. The actual overall process is generally not modeled explicitly; rather, one simply specifies what enters the box and what exits. The conventional models for DEA performance measurement are based on thinking about production/consumption as a "black box"(Färe and Grosskopf, 2000). This in fact does not suit the transit performance measurement application. Therefore this study modified and applied the network DEA model introduced by Färe and Grosskopt (1996) and the multiactivity DEA model developed by Mar Molinero (1996) to model both production and consumption activities in the transit firms. This offers a possibility to integrate consumption and production into a transit performance evaluation framework. Moreover, HB and UB are considered as two major production activities of a transit firm. Diez-Ticio and Mancebon(2002) advocate the use of multiactivity DEA technique as a more powerful shared inputs treating method. Thus allocation of shared input resources into the activities of the production and consumption processes is allowed. Furthermore, the network DEA performance evaluation framework is an appropriate concept which has an insight in the overall performance profile of the transit firm. That is to say, the combination of the production and consumption processes into one overall technology will provide insights into the inter-related effects between the two major processes of a transit firm. The network DEA basis of assessment provides the opportunity of exploring a simultaneous input minimization for production technique, and an output maximization for marketing strategy for the overall performance, which extends the typical cost effectiveness measure from the literature.

For the illustration of the network performance measurement, this study chooses to evaluate firm *k* relative to the network technology (8.1) by means of a directional distance function. This measure is as follows:

$$\vec{D}(x_k, y_k) = \max \theta_k = w_k^H \theta_k^H + w_k^U \theta_k^U + w_k^C \theta_k^C \tag{8.3}$$

s.t. $$\sum_{j=1}^{n} \lambda_j^H x_{aj}^{PH} \le (1-\theta_k^H) x_{ak}^{PH}, a = 1, \cdots, m_a,$$

$$\sum_{j=1}^{n} \lambda_j^U x_{bj}^{PU} \le (1-\theta_k^U) x_{bk}^{PU}, b = 1, \cdots, m_b,$$

$$\sum_{j=1}^{n} \mu_c \lambda_j^H x_{cj}^{PC} + \sum (1-\mu_c) \lambda_j^U x_{cj}^{PC}$$

$$\leq (1-\theta_{\mathrm{k}}^{\mathrm{H}})\mu_{\mathrm{c}} x_{Tk}^{PC} + (1-\theta_{\mathrm{k}}^{\mathrm{U}})(1-\mu_{\mathrm{c}}) x_{ck}^{PC}, c = 1,\cdots,m_c,$$

$$\sum_{j=1}^{n} \alpha_d^1 \lambda_{\mathrm{j}}^{\mathrm{H}} x_{dj}^{PCC} + \sum_{j=1}^{n} \alpha_d^2 \lambda_{\mathrm{j}}^{\mathrm{U}} x_{dj}^{PCC} + \sum_{j=1}^{n} \left(1-\alpha_d^1-\alpha_d^2\right) \lambda_{\mathrm{j}}^{\mathrm{C}} x_{dj}^{PCC}$$

$$\leq \theta_k^H \alpha_d^1 x_{dj}^{PCC} + \theta_K^U \alpha_d^2 x_{dj}^{PCC} + \theta_K^C \left(1-\alpha_d^1-\alpha_d^2\right) x_{dj}^{PCC}, d = 1,\cdots,m_d,$$

$$\sum_{j=1}^{n} \lambda_j^H y_{fj}^{PH} \geq y_{fk}^{PH}, f = 1,\cdots,s_f,$$

$$\sum_{j=1}^{n} \lambda_j^U y_{gj}^{PU} \geq y_{gk}^{PU}, g = 1,\cdots,s_g,$$

$$\sum_{j=1}^{n} \lambda_j^C y_{lj}^C \geq (1+\theta_k^C) y_{lk}^C, l = 1,\cdots,z_l,$$

$$\sum_{j=1}^{n} \lambda_j^C y_{oj}^C \geq (1+\theta_k^C) y_{ok}^C, o = 1,\cdots,z_o,$$

$$\sum_{j=1}^{n} \lambda_j^C x_{ej}^C \leq x_{ek}^C, e = 1,\cdots,m_e,$$

$$\sum_{j=1}^{n} \lambda_{\mathrm{j}}^{\mathrm{C}} y_{fj}^{PH} \leq y_{fk}^{PH}, f = 1,\cdots,s_f,$$

$$\sum_{j=1}^{n} \lambda_{\mathrm{j}}^{\mathrm{C}} y_{gj}^{PH} \leq y_{gk}^{PH}, g = 1,\cdots,s_g,$$

$$\lambda_j^H \geq 0, \lambda_j^U \geq 0, \lambda_j^C \geq 0, j = 1,\cdots,n,$$

$$w_k^H \geq 0, w_k^U \geq 0, w_k^C \geq 0,$$

$$\mu_c \geq 0, c = 1,\cdots,m_c,$$

$$\alpha_d^1 \geq 0, \alpha_d^2 \geq 0, d = 1,\cdots,m_d,$$

where $w_k^H + w_k^U + w_k^C = 1$.

The non-linear programming network DEA model in Eq (8.3), which is subject to the constraints, can be explained by each process as follows:

8.3.2.1 Production process constraints

The multiactivity DEA Model (Mar Molinero, 1996) can be applied to the determination of HB and UB efficiency at a set of transit firms in Taiwan. Some inputs will contribute only to the HB or the UB, while some other inputs will contribute to both the HB and the UB. The efficiency model in this process has an input contraction orientation and seeks to estimate the cost efficiency $(1-\theta_k^H)$ and $(1-\theta_k^U)$ of transit firm *k*. The assessment is pursued under a constant returns to scale assumption, while the objective is incorporated regarding the cost minimization characteristics of transit production, which is consistent with the concept proposed by Talley and Anderson (1981). This results in the following constraints:

Highway bus service:

$$\sum_{j=1}^{n} \lambda_j^H x_{aj}^{PH} \le (1-\theta_k^H) x_{ak}^{PH}, a = 1, \cdots, m_a, \tag{8.4}$$

$$\sum_{j=1}^{n} \lambda_j^H y_{fj}^{PH} \ge y_{fk}^{PH}, f = 1, \cdots, s_f, \tag{8.5}$$

Urban bus service:

$$\sum_{j=1}^{n} \lambda_j^U x_{bj}^{PU} \le (1-\theta_k^U) x_{bk}^{PU}, b = 1, \cdots, m_b, \tag{8.6}$$

$$\sum_{j=1}^{n} \lambda_j^U y_{gj}^{PU} \ge y_{gk}^{PU}, g = 1, \cdots, m_g, \tag{8.7}$$

Allocation of shared inputs to HB and UB:

$$\sum_{j=1}^{n} \mu_c \lambda_j^H x_{cj}^{PC} + \sum (1-\mu_c) \lambda_j^U x_{cj}^{PC} \le (1-\theta_k^H) \mu_c x_{ck}^{PC} + (1-\theta_k^U)(1-\mu_c) x_{ck}^{PC}$$

$$c = 1, \cdots, m_c, \tag{8.8}$$

where

x_{aj}^{PH}, y_{fj}^{PH} are quantities of inputs *a* and outputs *f* associated only with the HB activity of transit firm *j*.

x_{bj}^{PU}, y_{gj}^{PU} are quantities of inputs *b* and outputs *g* associated only with the UB activity of transit firm *j*.

x_{cj}^{PC} is quantities of inputs *c* associated with HB and UB at transit firm *j*.

λ^{H}, λ^{U} are positive constants associated with the HB production process and the UB production process.

μ_{c} is the proportion of the joint inputs *c* associated with the HB.

θ_k^H, θ_k^U are the maximum proportion inputs that can be reduced in the HB and UB activity, respectively, by transit firm *k*.

8.3.2.2 Consumption process constraints

The assessment of the service effectiveness of transit firms is based on an input-output set in which some inputs Y_f^{PH}, Y_g^{PU} are outputs of the production process, the characteristics and attributes are considered as intermediate inputs together with inputs X_d^{PCC}, such as management labor associated with HB, UB and the consumption process, and inputs X_e^C associated only with consumption in a consumption process, while the output $Y_l^C, Y_{\mathrm{o}}^{\mathrm{C}}$ are the passenger-kms and passengers, which are outputs of HB and UB activities of the production process consumed by passengers, respectively. The solution of this process yields θ_k^C which conveys information on the necessary adjustments to individual consumption outputs of each transit firm, based on the assumption of maximization of the ridership. This results in the following constraints:

Consumption process:

$$\sum_{j=1}^{n} \lambda_j^C x_{ej}^C \le x_{ek}^C, e = 1, \cdots, m_e, \tag{8.9}$$

$$\sum_{j=1}^{n} \lambda_{\mathrm{j}}^{\mathrm{C}} y_{fj}^{PH} \le y_{fk}^{PH}, f = 1, \cdots, s_f, \tag{8.10}$$

$$\sum_{j=1}^{n} \lambda_{\mathrm{j}}^{\mathrm{C}} y_{gj}^{PH} \le y_{gk}^{PH}, g = 1, \cdots, s_g, \tag{8.11}$$

$$\sum_{j=1}^{n}\lambda_j^C Y_{lj}^C \geq (1+\theta_{\mathrm{k}}^{\mathrm{C}}) Y_{lk}^C, l = 1,\cdots,z_l, \tag{8.12}$$

$$\sum_{j=1}^{n}\lambda_j^C y_{oj}^C \geq (1+\theta_{\mathrm{k}}^{\mathrm{C}}) y_{ok}^C, o = 1,\cdots,z_o, \tag{8.13}$$

Allocation of shared inputs to HB, UB and the consumption process:

$$\sum_{j=1}^{n}\alpha_d^1\lambda_{\mathrm{j}}^{\mathrm{H}} x_{dj}^{PCC} + \sum_{j=1}^{n}\alpha_d^2\lambda_{\mathrm{j}}^{\mathrm{U}} x_{dj}^{PCC} + \sum_{j=1}^{n}\left(1-\alpha_d^1-\alpha_d^2\right)\lambda_{\mathrm{j}}^{\mathrm{C}} x_{dj}^{PCC}$$
$$\leq \theta_k^H \alpha_d^1 x_{dj}^{PCC} + \theta_K^U \alpha_d^2 x_{dj}^{PCC} + \theta_K^C\left(1-\alpha_d^1-\alpha_d^2\right) x_{dj}^{PCC}, d = 1,\cdots,m_d, \tag{8.14}$$

where

x_{ej}^C is the quantity of inputs *e* associated only with the consumption activity of transit firm *j*

x_{dj}^{PCC} is the quantity of inputs *d* associated with HB, UB and consumption activity of transit firm *j*

α_d^1, α_d^2 are the proportion of joint inputs *d* associated with HB and UB, respectively

y_{lj}^C, y_{oj}^C are the quantities of outputs *l, o* associated only with the consumption activity of transit firm *j*

θ_k^C is the maximum proportion consumed outputs that can be expanded by transit firm *k*.

8.3.2.3 Environmental constraints

To further consider the effect of the environmental factors on the performance of transit firms, the environmental variables as were included non-discretionary inputs by imposing a restriction of the following form:

The effect of environmental factors on the consumption process:

$$\sum_{j=1}^{n}\lambda_{\mathrm{j}}^{\mathrm{C}} e_{wj}^C \leq e_{wk}^C, w = 1,\cdots,r_w, \tag{8.15}$$

where e_{wj}^C is quantities of environmental factors *w* associated only with the consumption activities of transit firm *j*.

The objective is to jointly maximize θ_k^H, θ_k^U and θ_k^C. The solution of Eq.(8.3) yields an overall measure of transit firm *k* which includes the HB cost efficiency $(1-\theta_k^H)$, UB cost efficiency $(1-\theta_k^U)$, service effectiveness $(1+\theta_k^C)$, and cost effectiveness $(1+\theta_k)$. The objective function takes the form:

Max $\theta_k = w_k^H \theta_k^H + w_k^U \theta_k^U + w_k^C \theta_k^C$

As is the case in the above equation, the coefficients w_k^H, w_k^U, w_k^C are associated with the priorities given to the two activities and processes, respectively. In order to emphasize the relative importance of each activity or process, the *ws* can be normalized so that they add up to one, e.g., $w_k^H + w_k^U + w_k^C = 1$. The assessed transit firm *k* will be termed efficient if and only if $\theta_k^H = \theta_k^U = \theta_k^C = 0$ in the optimal solution of Eq. (8.3~8.15). Since the model incorporates a process in the assessment, the results are useful for distinguishing cost efficiency, service effectiveness and cost effectiveness in consideration of the inter-related effects among these measures. In addition, the results are also useful for setting improvement targets for inefficient activities of the transit firm.

8.4 The data

In this study, drivers, vehicles, fuel and network length are used as specific inputs for both highway bus service and urban bus service, respectively; technical staff (mechanics) are used as shared inputs for both HB and UB; management staff as shared input for HB, UB and the consumption process; sales staff as a preassigned specific input for the consumption process; and population density and car ownership are used as two major environmental variables for the consumption process. The multiactivity DEA model will be applied to overcome the shared inputs issue. As for the output measure, vehicle-kms and frequencies of service are used as intermediate produced outputs for production process as well as for HB and UB respectively; and passenger-kms and passengers are used as final (consumed) output for consumption process as well as for HB and UB respectively.

The indicator data to be used in the measurement of cost efficiency, service effectiveness and cost effectiveness in Taiwanese motorbus transit is a sample of 24 firms, all long established operators and located all over the island in 2001. All these DMUs operated both HB and UB services. A system which provided only either HB or UB would therefore be excluded. All data used in the modified network model were obtained from the annual statistical reports published by the National Federation of Bus Passenger Transportation of the Republic of China for 2002.

A modification of the network DEA model introduced by Färe and Grosskopf (1996) is proposed, and the multiactivity DEA model developed by Mar Molinero (1996) as well as Fielding's theory is also incorporated into this all-in-one model to investigate the multimode transit performance. The modified network model represents two production and one consumption nodes, as well as intermediate products between the production node and consumption node in the multimode bus transit technology. The modified network DEA model is applied to estimate the efficiency or effectiveness of the multimode bus transit systems, in which the shared inputs used could be allocated to each node (activity), and the optimal proportion of shared inputs used may vary from one firm to another. Thus the optimal proportions in the modified model are derived from the data instead of being fixed in advance. (This differs from Löthgren and Tambour (1999), where a network model with its allocation data was based on budget data in terms of percentage of total labor hours). Then Fielding's three important indicators (1987) corresponding to the characteristics of the production process coinciding with the consumption process in the transit system are presented. In addition, the transit performance is thought to be sensitive to the environment in which the system operates, and hence environmental factors that affect performance must be identified and taken into account (Giuliano, 1981).

In the modified model, inputs $x_{aj}^{PH} \in R_{+}^{m_a}$ such as drivers are used in the production node of HB to produce intermediate output $y_{fj}^{PH} \in R_{+}^{s_f}$ such as vehicle-kms. This intermediate output y_{fj}^{PH} is used as input together with x_{e}^{C} and $x_{e}^{C} \in R_{+}^{m_z}$ such as sales staff in the consumption node to produce final output $y_{l}^{C} \in R_{+}^{z_l}$ such as passenger-kms. The same method can be applied to the urban bus service. The network relationship among netput is illustrated in Figure 8.3. The production technology of the multimode bus transit is represented using proxies for inputs and outputs of each of the two modes, that is, eight specific inputs (four for HB and the other four for UB), two shared inputs and two environmental variables; two intermediate outputs and two final outputs. The following set of variables, labeled according to the relationships in Figure 8.3, are used in the empirical application for each mode.

Inputs for highway bus service (x_{a}^{PH}): The four specific inputs are given by $x_{d}^{PH} = \text{DRIVER}$ (the number of transportation labor used by this mode in providing service), $x_{v}^{PH} = \text{VEHICLE}$ (the fleet sizes, which are taken to be the total number of vehicles operated in maximum service by this mode), $x_{f}^{PH} = \text{FUEL}$ (the number of liters of fuel by mode) and $x_{l}^{PH} = \text{NWLTH}$ (network length by mode).

Shared inputs (x_{d}^{PCC}, x_{c}^{PC}): These are given by $x_{m}^{PCC} = \text{MGT}$ (the number of management labor used by two modes and the consumption node), and $x_{t}^{PC} = \text{MEC}$ (the number of mechanics used by two modes). The data includes a preassigned specific input (x_{e}^{C}), sales staff, $x_{s}^{C} = \text{SALE}$ for each firm in terms of the number of sales labor devoted to the consumption node in the network model. The allocation of these data are based on the resulting data being derived from the application of the multiactivity DEA model, which is capable of objectively assigning a share to the different activities/processes which will allow for the independent treatment of each of these different activities/processes. This information allows a separation of the shared inputs, which is necessary for an implementation of the modified network model.

Inputs for urban bus service (x_b^{PU}): In the same manner as the highway bus service, the three individual inputs for urban service are given by $x_d^{PU} = \text{DRIVER}$ (the amount of transportation labor used by this mode in providing service), $x_v^{PU} = \text{VEHICLE}$ (the fleet sizes, which are taken to be the total number of vehicles operated in maximum service by mode), $x_f^{PU} = \text{FUEL}$ (the number of liters of fuel by mode) and $x_l^{PU} = \text{NWLTH}$ (network length by mode).

Outputs for highway bus service (y_f^{PH}): The intermediate output is given by y_h^{PH}=VEHKM (vehicle-kms) and the final output（y_h^C） is given by y_h^C=PASSKM (passenger-kms).

Outputs for urban bus service (y_g^{PU}): In the smae manner as the highway ubs service, the intermediate output is given by y_u^{PU}=FREQ (frequencies of service) and the final output（y_o^C）is given by y_u^C=PASS (passengers).

Environmental variables (e_w^C): Following Levaggi (1994) and Chu *et al*. (1992), two environmental factors are considered in this paper. There is a set of “environmental factors” including $e_c^C = \text{CAR}$, $e_p^C = \text{POP}$ (the quantities of car ownership and population density influencing the consumption process), to describe the situation in which the DMU finds itself.

Table 8.1 presents 17 netput used in this study to capture the cost efficiency, service effectiveness and cost effectiveness. Table 8.2 shows the summary statistics.

Table 8.1 Inputs and Outputs Measures Used in the Model

	Specific inputs	Shared inputs	Intermediate outputs of production process	Final outputs of consumption process	Environmental variables of consumption process
Production process of highway bus service	Drivers: x_d^{PH} =DRIVER Vehicles: x_v^{PH} =VEHICLE Fuel: x_f^{PH} =FUEL Network Length: x_l^{PH} =NWLTH	Managements: x_m^{PCC} =MGT (Shared inputs to HB, UB and consumption process)	Vehicle-kms: y_h^{PH} =VEHKM	Passenger-kms: y_h^{C} =PASSKM	Car ownership: e_c^{C} =CAR
Production process of urban bus service	Drivers: x_d^{PU} =DRIVER Vehicles: x_v^{PU} =VEHICLE Fuel: x_f^{PU} =FUEL Network Length: x_l^{PU} =NWLTH	Mechanics: x_t^{PC} =MEC (Shared inputs to HB and UB)	Frequency: y_u^{PU} =FREQ	Passengers: y_u^{C} =PASS	Population density: e_p^{C} =POP
Consumption process	Sale Staff: x_s^{C} =SALE				

Table 8.2 Variables and Descriptive Statistics

	Mean	Stdev	Maximum	Minimum
Individual inputs				
Process of HB service				
DRIVER	158.1	137.0	451.0	8.0
VEHICLE	121.0	107.8	387.0	8.0
FUEL	3,084,916.9	2,431,013.4	8,154,152.0	281,700.0
NWLTH	1,248.2	1,134.0	3,765.9	31.4
Process of UB service				
DRIVER	137.2	175.1	633.0	3.0
VEHICLE	120.3	145.2	557.0	3.0
FUEL	3,386,796.7	4,857,287.8	16,362,765.0	44,381.0
NWLTH	248.5	228.9	1,006.5	18.0
Shared inputs				
MEC	39.6	32.3	117.0	3.0
MGT	31.3	39.6	193.0	1.0
Intermediate outputs				
VEHKM	8,533,146.4	6,956,059.8	25,378,595.3	775,231.7
FREQ	790,040.5	1,131,977.4	4,115,662.0	14,540.0
Final outputs				
PASSKM	103,807,107.6	109,260,433.4	417,903,218.0	5,189,557.0
PASS	20,446,874.1	30,453,096.6	105,091,579.0	76,818.0
Environmental variables				
CAR	222.7	17.3	249.7	191.4
POP	4,016.2	3,252.5	11,864.0	73.0

8.5 Results and discussions

There are a number of results can be found with regard to the all-in-one network model, and separate the conventional DEA model for measuring performance. In this section the results obtained are summarized in Table 8.3 will be comment. Recall that if the value of the cost efficiency ($\theta_k^P = 1-(\frac{\theta_k^H + \theta_k^U}{2})$) is equal to unity, it denotes 'efficient', whereas values less than 1 denote 'inefficient'. On the other hand, if the value of the service effectiveness ($1+\theta_k^C$) or cost effectiveness $(1+\theta_k)$ equals to unity, it denotes 'effective', whereas values greater than 1 denote 'ineffective'. For each transit firm eight performance measures were calculated. The three basic measures that were obtained by the network model, θ_k^H, θ_k^U and θ_k^C as well as the other two induced measures $\theta_k^P = 1-(\frac{\theta_k^H + \theta_k^U}{2})$ and $\theta_k = 0.25\theta_k^H + 0.25\theta_k^U + 0.5\theta_k^C$ are portrayed in Table 8.3. In the first two columns the HB and UB activity cost efficiency, and in the fourth column the service effectiveness are evaluated on the basis of their ability to share common inputs among different activities, and determine simultaneously the efficiency and effectiveness. This is a credible concept, and from this viewpoint the results make clear that among the 24 transit firms measured, only 7, those ofTable 8.3 Efficiency or effectiveness scores of the network model Ta-you, Fu-ho, Kuang-hua, Tamshui, Chungli, Fengyuan and Pingtung can be considered as cost efficient, which is shown in the third column of Table 8.3. If highway bus services are concentrated on, as shown in the first column, then the bus services of 8 of the transit firms demonstrated a productive behavior superior to the rest. Regarding the urban bus services, a maximum level of efficiency was achieved by 10 transit firms, with DMUs that were efficient in each of the two services corresponding in only seven cases, i.e., Ta-you, Fu-ho, Kuang-hua, Tamshui, Chungli, Fengyuan, Pintung.

Table 8.3 Efficiency or Effectiveness Scores of the Network Model

	Highway bus Efficiency $(1-\theta_k^H)$	Urban bus Efficiency $(1-\theta_k^U)$	Cost Efficiency (θ_k^P)	Service Effectiveness $(1+\theta_k^C)$	Cost Effectiveness $(1+\theta_k)$
Ta-you	1.000	1.000	1.000	1.000	1.000
Fu-ho	1.000	1.000	1.000	1.000	1.000
Chung-hsing	0.692	0.899	0.796	1.153	1.179
Chih-nan	0.964	0.748	0.856	1.000	1.072
Kuang-hua	1.000	1.000	1.000	1.000	1.000
Tamshui	1.000	1.000	1.000	1.000	1.000
Hsin-ho	0.865	1.000	0.933	1.118	1.093
Taipei	0.996	0.949	0.973	1.000	1.014
Sanchung	0.786	1.000	0.893	1.000	1.053
Capital	0.966	0.986	0.976	1.000	1.012
Hsintien	0.995	0.998	0.997	1.000	1.002
Hualien	0.941	0.870	0.906	1.000	1.047
Taoyuan	0.822	1.000	0.911	1.000	1.045
Chungli	1.000	1.000	1.000	1.000	1.000
Hsinchu	0.929	0.975	0.952	1.000	1.024
Fengyuan	1.000	1.000	1.000	1.000	1.000
Chu-yeh	0.753	0.747	0.750	1.000	1.125
Taichung	0.760	0.550	0.655	1.187	1.266
Jen-you	0.837	0.449	0.643	1.000	1.179
Changhua	0.887	0.507	0.697	1.000	1.152
Chiayi	0.857	0.680	0.769	1.113	1.172
Tainan	0.903	0.491	0.697	2.227	1.765
Kaohsiung	1.000	0.514	0.757	1.000	1.122
Pingtung	1.000	1.000	1.000	1.000	1.000
Maximum	1.000	1.000	1.000	2.227	1.765
Minimum	0.692	0.449	0.643	1.000	1.000
Mean	**0.915**	**0.848**	**0.882**	**1.075**	**1.097**
Median	0.953	0.981	0.922	1.000	1.046
Stdev	0.097	0.204	0.126	0.252	0.162

Note: (1) $\theta_k^P = 1 - (\frac{\theta_k^H + \theta_k^U}{2})$

(2) $\theta_k = 0.25\theta_k^H + 0.25\theta_k^U + 0.5\theta_k^C$

Regarding average efficiency, it is worth noting that this clearly differs between the two activities, with the highway bus service showing a higher average rate of efficiency. The priority given by transit firms to this type of service, because of the greater returns in profit for operating them, could be one of the reasons for explaining this phenomenon.

With regard to the service effectiveness measure, 19 out of 24 are categorized effective transit firms, while only 5 are categorized as ineffective. When the mean service effectiveness score is greater than 1 (1.075) it denotes 'ineffective' for the sample as a whole. As to the cost effectiveness measure, it is found that only six ranked as effective while the other 18 ranked as ineffective firms. The average cost effectiveness was also greater than 1 (1.097) indicating 'ineffective' for the sample.

These network results are very much different when the transit firm performance is judged on the basis of separate measures of cost efficiency, service effectiveness and cost effectiveness, terms which are described in previous literatures following the interpretations proposed by Fielding (1987). There is one further point that deserves discussion. It would be reasonable to compare the rates obtained from the network model with those derived from a conventional DEA model. In the latter no regard is given to the possible technological differences of the various activities engaged in by multimode transit firms, integrating them into one single measurement model, nor are the cost efficiency, service effectiveness and cost effectiveness determined simultaneously. The results of the comparison are set out in Table 8.4.

In order to provide statistically robust findings concerning the firms' performance, the paired difference experiments are applied. This experiment is conducted to verify whether the sample firms of the two kinds of models were drawn from the same performance populations for the three measures, respectively. The significance of the t-values is set as a two-tailed test at 0.025 acceptance level. As shown in the last column of Table 8.4, the test of significance yielded a t-value of 2.894, which shows a statistically significant difference

Table 8.4 Descriptive Statistics of the Conventional and Network Models' Performance Scores and the Results of Test of Significance

	Network model				Conventional model				Test of significance
	Number of firms	Number of efficient or effective firms	Number of inefficient or ineffective firms	Mean of efficiency or effectiveness scores	Number of firms	Number of efficient or effective firms	Number of inefficient or ineffective firms	Mean of efficiency or effectiveness scores	Statistics
All samples	72	33	39	-	72	43	29	-	t-value 2.341 p-vaule 0.022*
Cost efficiency	24	7	17	0.882	24	12	12	0.949	t-value 2.894 p-vaule 0.008*
Service effectiveness	24	19	5	1.075	24	16	8	1.136	t-value 1.973 p-vaule 0.061
Cost effectiveness	24	7	17	1.097	24	15	9	1.079	t-value 0.69 p-vaule 0.497

Note: (1) Paired difference experiments are used to test the same mean between two groups. The null hypothesis is that there is no significant difference in the efficiency or effectiveness scores between network model and standard model. The alternative hypothesis is that there is significant difference in the efficiency or effectiveness scores between network and standard model.

(2) t-value is calculated by

$$t = \frac{\bar{x}_D - 0}{S_D / \sqrt{N_D}}$$

where $\bar{x}_D$ = the difference of sample mean.

S_D = the deviation of $\bar{x}_D$

N_D = the number of sample

(3) "*" means significant at 5% level of significance.

in cost efficiency measure. However, the statistical test confirms they are not significantly different in both service effectiveness measure and cost effectiveness measure, having t-values of 1.973 and 0.690, respectively. On the other hand, the statistical test for the entire sample, which pools the three measures in a set, yields a t-value of 2.341 which shows a significant difference between the two models. The results of statistical tests for the two models may imply that they are generally insignificantly different. Therefore some more means such as rank comparison are applied for further comparison.

To emphasize the comparison, six efficiency or effectiveness measurements are examined. They are shown in Table 8.5. The network cost efficiency indices in the second column of Table 8.5 have slightly larger efficiency score ranges, from 0.643 to 1.0; and 16 of the 24 firms in the sample are less efficient relative to the conventional cost efficiency. An examination of Table 8.5 reveals that there are only 7 of the 24 firms operating in the frontier under the network DEA model: Ta-you, Fu-ho, Kuang-hua, Tamshui, Chungli, Fengyuan and Pingtung, while 8 of the 24 are operating in the frontier under conventional models: Fu-ho, Kuang-hua, Taipei, Sanchung, Capital, Hualien, Hsinchu and Changhua. With respect to service effectiveness, it shows a relatively lower effectiveness score range, from 1.0 to 2.227; and only 2 out of the 24 in the sample are less effective than the conventional service effectiveness. As to cost effectiveness, it also indicates a relatively lower effectiveness score range, from 1.0 to 1.765; and 16 of the 24 firms in the sample are less effective than the conventional cost effectiveness. This shows that considering the multiactivity and unstorable characteristics of transit services in the network model, it allows firms to compare their performance with peer groups under a practical and realistic condition. The next conclusion that can be drawn from Table 8.5, is that a ranking of a firm’s performance by network model, which acknowledges the multiactivity and unstorable characteristics of transit service, is very different from a ranking of that firm’s performance by conventional model, which ignores the multiactivity and unstorable

Table 8.5 Comparison of the Conventional and Network Models' Performance Scores

	COST EFFICIENCY					SERVICE EFFECTIVENESS					COST EFFECTIVENESS				
	Conventional model		Network model		Inter-related effect	Conventional model		Network model		Inter-related effect	Conventional model		Network model		Inter-related effect
Ta-you	1.000	(1)	1.000	(1)	1.000	1.108	(18)	1.000	(1)	0.903	1.000	(10)	1.000	(18)	1.000
Fu-ho	1.000	(1)	1.000	(1)	1.000	1.000	(1)	1.000	(1)	1.000	1.000	(10)	1.000	(18)	1.000
Chung-hsing	1.000	(1)	0.796	(17)	0.796	1.150	(19)	1.153	(22)	1.003	1.016	(8)	1.179	(3)	1.160
Chih-nan	0.890	(19)	0.856	(16)	0.962	1.000	(1)	1.000	(1)	1.000	1.019	(7)	1.072	(10)	1.052
Kuang-hua	1.000	(1)	1.000	(1)	1.000	1.000	(1)	1.000	(1)	1.000	1.000	(10)	1.000	(18)	1.000
Tamshui	1.000	(1)	1.000	(1)	1.000	1.578	(23)	1.000	(1)	0.634	1.139	(4)	1.000	(18)	0.878
Hsin-ho	1.000	(1)	0.933	(12)	0.933	1.283	(22)	1.118	(21)	0.871	1.031	(6)	1.093	(9)	1.060
Taipei	1.000	(1)	0.973	(10)	0.973	1.000	(1)	1.000	(1)	1.000	1.009	(9)	1.014	(15)	1.005
Sanchung	1.000	(1)	0.893	(15)	0.893	1.000	(1)	1.000	(1)	1.000	1.000	(10)	1.053	(11)	1.053
Capital	1.000	(1)	0.976	(9)	0.976	1.000	(1)	1.000	(1)	1.000	1.000	(10)	1.012	(16)	1.012
Hsintien	0.974	(15)	0.997	(8)	1.023	1.000	(1)	1.000	(1)	1.000	1.000	(10)	1.002	(17)	1.002
Hualien	1.000	(1)	0.906	(14)	0.906	1.000	(1)	1.000	(1)	1.000	1.000	(10)	1.047	(12)	1.047
Taoyuan	0.966	(16)	0.911	(13)	0.943	1.000	(1)	1.000	(1)	1.000	1.000	(10)	1.045	(13)	1.045
Chungli	0.753	(24)	1.000	(1)	1.328	1.000	(1)	1.000	(1)	1.000	1.276	(3)	1.000	(18)	0.784
Hsinchu	1.000	(1)	0.952	(11)	0.952	1.000	(1)	1.000	(1)	1.000	1.000	(10)	1.024	(14)	1.024
Fengyuan	0.959	(17)	1.000	(1)	1.043	1.000	(1)	1.000	(1)	1.000	1.000	(10)	1.000	(18)	1.000
Chu-yeh	0.854	(21)	0.750	(20)	0.878	1.000	(1)	1.000	(1)	1.000	1.000	(10)	1.125	(7)	1.125
Taichung	0.874	(20)	0.655	(23)	0.749	1.257	(21)	1.187	(23)	0.944	1.059	(5)	1.266	(2)	1.195
Jen-you	0.820	(22)	0.643	(24)	0.784	1.000	(1)	1.000	(1)	1.000	1.446	(2)	1.179	(3)	0.815
Changhua	1.000	(1)	0.697	(21)	0.697	1.000	(1)	1.000	(1)	1.000	1.000	(10)	1.152	(6)	1.152
Chiayi	0.957	(18)	0.769	(18)	0.803	1.005	(17)	1.113	(20)	1.107	1.000	(10)	1.172	(5)	1.172
Tainan	0.772	(23)	0.697	(21)	0.903	2.634	(24)	2.227	(24)	0.845	1.911	(1)	1.765	(1)	0.924
Kaohsiung	0.984	(13)	0.757	(19)	0.769	1.000	(1)	1.000	(1)	1.000	1.000	(10)	1.122	(8)	1.122
Pingtung	0.983	(14)	1.000	(1)	1.017	1.245	(20)	1.000	(1)	0.803	1.000	(10)	1.000	(18)	1.000
Maximum	1.000		1.000		1.328	2.634		2.227		1.107	1.911		1.765		1.195
Minimum	0.753		0.643		0.697	1.000		1.000		0.634	1.000		1.000		0.784
Mean	0.949		0.882		0.930	1.136		1.075		0.963	1.079		1.097		1.026
Stdev	0.078		0.126		0.130	1.000		1.000		1.000	1.000		1.046		1.018

Note: The figure in the parenthesis stands for the firm's ranking order characteristics of the transit service. In terms of cost efficiency, the ranking of the firms of the two models diverge so greatly that more than half the firms are given different results. Service effectiveness has a higher similarity in ranking relative to the other two measures. The two models, network and conventional model, do not imply a similar close ranking in cost effectiveness. It follows that failure to credit firms for their multiactivity and unstorable characteristics can severely distort the ranking of a firm's performance. On the whole, the two models give different results in terms of rank comparisons across the three measures, despite the statistically insignificant differences mentioned above. It is more reasonable to believe the results of the network model. It also turns out that this approach yields not only a different efficiency but also a different ranking.

As can be noted, the application of the network model results in a much lower number of efficient or effective units, except in the service effectiveness measure; as well as a lower average efficiency or effectiveness, except for the cost effectiveness measure. Besides, it is apparent that the DMUs that are both effective and efficient in each of the three measures of these two models coincide in only two firms, Fu-ho and Kuang-hua.

As an additional experiment to investigate the inter-related effects, this study calculates an inter-related ratio. Implicit adjustment terms can be defined as the ratio of the network estimates of efficiency and the effectiveness divided by the corresponding conventional estimates, and can be named the inter-related effect. If this ratio is greater (less) than unity for the cost efficiency measure, then the effect of accounting for multiactivity and unstorable characteristics is positive (negative), and the measured efficiency is higher (lower) when accounting for multiactivity and unstorable characteristics. On the other hand, if this ratio is greater (less) than unity for service effectiveness or cost effectiveness measures, the effect of accounting for multiactivity and unstorable characteristics is negative (positive), and the measured effectiveness is lower (higher) when accounting for multiactivity and unstorable characteristics. The results are displayed in the third, sixth and ninth column of Table 8.5.

Comparisons of these results obtained from the two models indicate how the inclusion of the multiactivity and the unstorable characteristics of the transit service (based on the network model) affects the estimated efficiency and effectiveness scores. As can be seen, the inter-related ratio is on average less than unity for cost efficiency measure, and therefore this study draws the conclusion that the network model lowers the estimated cost efficiency for this sample. It must be noted that the inter-related ratio is on average less than unity for the service effectiveness measure, therefore this study concludes that the network model increases the estimated service effectiveness for this sample. However, the inter-related ratio is on average greater than unity for cost effectiveness measure, and this study can therefore conclude, from the above assumption, that the network model lowers the estimated cost effectiveness for this sample.

The results obtained from the network model and the conventional model are quite different in terms of the number of efficient or effective units, rank comparisons of DMUs performance, as well as inter-related effects. In general, the network model is more demanding than the conventional model. This is explained by the following two facts. First, the achievement of a better efficiency or effectiveness in the network model requires that good productive and consumption matching behaviors be demonstrated on the part of the two services as well as between production and consumption process, respectively. However with the conventional model it is possible for there to be compensations between the two activities and processes in such a way that one DMU will always achieve the production frontier provided that, in global terms, it demonstrates behavior which is superior to the rest, even if such superiority is not produced in all the activities (services) it carries out. Second, a representation of both production and consumption technologies in a unified framework is allowed in the network model, and hence the three measures interact to determine the performance, while with the conventional model the three measures are calculated independently.

8.6 Conclusions

Cost efficiency alone captures the performance of a transit firm as described in terms of tangible inputs and outputs. The conventional DEA model evaluates the cost efficiency with which a transit firm transforms inputs into outputs. It assumes that the transit firm is equally efficient in all its activities. However, there are instances in which a transit firm faces several production functions, which is the case when a transit firm is engaged in several activities simultaneously. Therefore it is necessary to account for the performance of each activity. However, as indicated by Tomazins (1975) the services produced by the transportation system are not retainable or transferable, they must be consumed at the time and place produced, or not consumed at all. This perishability of the commodity produced, and the fact that only a proportion of the services produced are actually consumed, bring into question whether performance studies from the point of view of the producer alone can suffice. Obviously, a combination of production process and consumption process into an overall process is a more suitable way to evaluate transit system performance.

In this study, performance evaluation concepts concerning the transit services have been reinterpreted in light of the technological differences within multimode transit firms, as well as the unstorable characteristics of transportation system. It appears that the multiactivity approach is better suited to shared inputs allocation to optimize the input proportion. Including this approach into the network DEA model is more appropriate for bringing production and consumption processes together as a single model in order to determine cost efficiency, service effectiveness and cost effectiveness simultaneously. Overall, this paper succeeded in putting forward the concept of differentiating the treatment given to the shared inputs from those that are specific to each service, and determining three measures at different processes simultaneously in an attempt to bridge the gap between the methodologies of performance assessment and unstorable characteristics in multimode transit services.

The benchmarking of cost efficiency, service effectiveness, and cost effectiveness across transit firms can be operationalized in the network DEA framework by employing a multiactivity DEA model. The outputs used in this model are the same as in the traditional one. However, the results of the extended model are more practical and more realistic. The all-in-one network model allows the identification of best-practice transit firms that perform well in all the performance dimensions simultaneously. And, the performance of other transit firms can be benchmarked with respect to the best-practice transit firms thus identified.

The results obtained from the network model and a conventional model are quite different in terms of the number of efficient or effective units, rank comparisons of DMUs performance as well as inter-related effects. In general, the network model is more demanding than the conventional model. This has been explained by the aforementioned two facts which are a novel contribution introduced for the first time in the transportation sector.

CHAPTER 9

Summary and Policy Implications

This is a dissertation on a policy-relevant topic (privatization, efficiency, effectiveness, etc.), using state-of-the-art, innovative techniques. It includes not only allocative efficiency (price distortions) without requiring information on prices and overall risk-adjusted efficiency incorporating desirable and undesirable outputs, but also the shared inputs and unstorable characteristics of transportation service. Both these aspects are very unusual in transport analysis. Moreover, two of the analyses have been carried out for a situation before and a situation after privatization, while the other two have performed concerning a set of multimode bus firms. Throughout the dissertation, the non-parametric technique, also known as DEA, was used as the common approach which integrates the four essays into a dissertation.

This final chapter examines the contributions of this dissertation to the literature first, followed by a summary of this dissertation, and policy implications of the dissertation. Area for further research is finally discussed.

9.1 Contributions to the literature

This dissertation makes a contribution to understanding of transit performance measurement in several ways. The first essay contributes to the literature on four counts. First, because profit margins relate directly to cost effectiveness which measures the relationship between the cost of producing a service and in consumption, it is more appropriate to apply the hyperbolic graph efficiency approach rather than an input-oriented or output-oriented measure, or both to efficiency measurement. Second, by decomposing “the return to the dollar” rather than overall economic efficiency into technical efficiency and allocative efficiency. One is able to focus not only on the TE measure, but also take the AE measure into account. Third, to measure the changes of "return to the dollar" (profitability or profit margin), one can estimate the "return to the dollar" growth which equals the technical efficiency change multiplied by alloctive efficiency change. In this way, allocative efficiency can be obtained in order to capture price distortions without requiring information on prices. Fourth, A description of a holistic framework for efficiency measures that enables the mapping of the impact of privatization on TMTC's performance.

The major contribution of the second essay to the literature is that, to the present author's knowledge, the concept of transport risk as an undesirable output is, for the first time, introduced in the field of bus transit. As well, the overall risk-adjusted efficiency changes following privatization is estimated by treating transport risk as a joint but undesirable output. The third essay contributes to our understanding of objectively assigning the shared variables to the different activities (services), and thereby estimating the efficiency of individual services within different but highly homogeneous multimode transit firms which engage in their services with non-identical technologies and use shared inputs.

Particular contributions of the fourth essay are:

1. An outline of a comprehensive framework for performance measures that enable our understanding of productive and consuming processes, or even the market mechanism.
2. Aside from putting forward the concept of differentiating the treatment given to the shared inputs from those that are specific to each service, this study determine three measures (i.e., cost efficiency, service effectiveness and cost effectiveness) at different production and consumption processes simultaneously in an attempt to bridge the gap between the methodologies of performance assessment and unstorable characteristics in multimode transit services.
3. This is a novel assessment of transit performance using a network DEA model as compared to methodologies used in a variety of previous studies on transit systems.

One advantage of the DEA methodology is that it provides a comprehensive picture and evaluation of organizational performance, without the constraints and assumptions of the SFA. Another is the ease with which multiple inputs and outputs can be handled simultaneously without making judgments on their relative importance in an industry such as bus service. Finally, this nonparametric technique does not impose any behavioral assumptions nor does it specify any particular functional from for either the cost or production function, or for the error terms associated with frontier function estimation.

On the other hand, the main limitation of nonparametric techniques is that they do not make any assumption regarding the stochastic properties of the data, rendering statistical confidence interval testing of the results impossible.

Moreover, due to a short-term evolutions of performance study using limited data, this preliminary confirmation still need further data of longer period to provide further evidence, especially regarding to the technical efficiency change.

9.2 Summary

The 1996 new legislation concerning the partial deregulation of bus industry led to a major structural change in the whole industry in Taiwan and provide a new framework for all bus operation. This dissertation has studied the effects of privatization and regulatory changes in the public transport industry, with special reference to changes in efficiency and/or effectiveness. On one hands, the TMTC's privatization programme offers a unique opportunity to analyze the effects on the efficiency changes of its kind. On the other hand, a number of long established operators, most of them are so-called multimode transit firms, seem to have worked effectively, and still survives following deregulation. Therefore there is a requirement to examine carefully transit performance based on the concepts of efficiency and/or effectiveness.

This dissertation is composed of four stand-alone essays which deal with four crucial but often neglected issues concerning transit performance, with particular reference to Taiwanese bus transit industry. The first two essays pertain to the impact of privatization on bus firm's efficiency and talk about to what extent the various efficiency changes before and after privatization.

The last two essays shift the focus from investigating the influence of privatization on the transit firm to the efficiency measurement of some transportation organizations which engage in various activities (services) simultaneously, such as multimode bus transit.

Specifically, four research objectives corresponding to four essays are addressed in this dissertation, respectively.

First, measure the "return to the dollar" at the station-level of TMTC before and after privatization and decompose it into technical and allocative efficiency indexes, and then estimate further the price distortions by allocative efficiency which using data on observed costs and revenues without requiring explicit informance on prices, unlike that traditional approach does.

Second, apply a model which incorporates both desirable and undesirable outputs to examine the impact of privatization experienced by the TMTC. And transport risks as undesirable outputs are taken into account to measure the overall risk-adjusted efficiency changes.

Third, explore the efficiency of individual services within different but highly homogeneous multimode transit firms which engage in their various services with non-identical technologies and use shared inputs.

And lastly, fill a void in the literature by presenting a model that allows a representation of both production and consumption technologies in a unified framework, and hence can be used to simultaneously estimate the cost efficiency, service effectiveness and cost effectiveness of multimode transit firms which carry out their services with non-identical technologies using common inputs.

This dissertation discussed several methods of efficiency and/or effectiveness analysis finding both their effectiveness and limitations in the four case studies. The first essay is to describe a case study in which a hyperbolic graph efficiency approach is applied to measure "return to the dollar" at the station-level of TMTC before and after privatization. The "return to the dollar" measure is decomposed into two components: a technical efficiency index and allocative efficiency index. Price distortions are measured by allocative efficiency using data on observed costs and revenues without requiring explicit information on prices.

A directional distance function which incorporates both desirable and undesirable outputs is employed in the second essay to investigate the impact of privatization experienced by the TMTC. For the first time, transport risk is treated as a joint but undesirable output to measure efficiency changes following privatization.

In the third essay of the dissertation, the multiactivity DEA model is applied to explore the efficiency of individual services within different but highly homogeneous multimode transit firms in Taiwan, due to its being designed, in particular, to estimate the efficiency achieved by organizations which face several production functions using shared inputs.

Following Fare and Grosskopf (1996, 2002), the fourth essay presents an approach to include both the unstorable characteristics of transportation service and the technological differences within multimode transit firms in efficiency and effectiveness measurement. The proposed network DEA model differs from conventional models in two respects: First, the consumed services occurring concurrently with the produced services are explicitly taken into account, and second, the network model allows a representation of both production and consumption technologies in a unified framework and hence can be used to simultaneously esitimate the cost efficiency, the service effectiveness and the cost effectiveness of multimode transit firms which carry out their services with non-identical technologies and use shared inputs.

The proposed network DEA model is applied to production and consumption data for a sample of multimode bus transit firms in Taiwan. Of the 60 bus companies in Taiwan, 24 of them operated both highway bus services (HB) and urban bus services (UB) in 2001. This is a novel assessment of transit performance using a network DEA model as compared to methodologies used in a variety of previous studies on transit systems.

There are two categories of sample data used in this dissertation. First, data used in the first two essays come from both TMTC and KKTC's annual statistical reports and accounts and are supplemented by further data requested from both operators. Since both TMTC and GGBE were undoubtedly undergoing a degree of "privatization turmoil," characterized by a fundamental shake-up, changing business or working practices, and employees entering and leaving firms, the data for the year of privatization (i.e., 2001) are excluded to avoid any possible bias. In addition, no significant reforms appear to have taken after the year of structural changes in KKTC. Therefore, this study uses TMTC station-level data in the period of 2000 and KKTC data for 2002. Second, as for the last two essays, the indicator data to be used in the measurement of efficiency in Taiwan's bus transit system is a sample of 24 firms, all long established operators and located all over the island in 2001. All these DMUs operated both HB and UB. A system which provided only either HB or UB is excluded. All data used in the multiactivity DEA model were obtained from the annual statistical reports published by the National Federation of Bus Passenger Transportation of the Republic of China for 2002.

The main results of this dissertation based on the four case studies are as follows.

First, the decomposition results indicated that both technical and allocative efficiencies contribute to the growth of "return to the dollar", with the allocative component playing a more important role than the technical component. Perhaps in an attempt to cover the inefficiency-induced losses, both the public and private firms apparently resort to distorting relative output prices with respect to input prices, and the distortion is more pronounced in the private firm than in the public firm. A statistically significant increase in technical efficiency took place following privatization, implying that the private firm converted input resources into output more effectively than its predecessor.

Second, using a directional output distance function which incorporates both desirable and undesirable output to investigate the impact of privatization experienced by the TMTC, the empirical results demonstrate that TMTC's privatization has produced a distinct improvement in efficiency enhancement and as such may be considered to be a source of cost reductions.

Third, to determine the efficiency of individual services within different but highly homogeneous multimode transit firms which engage in their services with non-identical technologies and use shared inputs. The empirical findings indicate that the multiactivity model is more demanding than the conventional DEA model and thereby shows itself to be an especially useful instrument in performing this task.

Fourth, subsequent to previous results, the results obtained from the network model compared to those of a conventional model are quite different in terms of the number of efficient or effective units, rank comparisons of DMUs performance as well as inter-related effects. Generally speaking, the network model is more demanding than the conventional model.

9.3 Policy implications of the dissertation

The results obtained from this dissertation have some important policy and managerial implications for the bus industry.

1. Efficiency improvement

   As indicated by Gomez-ibanez and Meyer (1993), a primary motivation of government privatization has been a widespread belief that the private sector is inherently more efficient than the public sector (the so-called property right theory). A private managed enterprise, motivated by the possibility of profit, may have strong incentives to be more cost conscious, efficient and customer oriented than a public enterprise.

The decomposition of the "return to the dollar" indicates that this increase in profit magin was most attributed to allocative progress rather than to an improvement in technical efficiency. Recall that technical efficiency reflects the ability of a firm to obtain maximal output from a given set of inputs, and allocative efficiency provides information on how the available resources are allocated among the various inputs, that is, transit fleet, labor, and fuel in the supply of transit services. Two important implications can be drawn from this result. First, the improved components of a firm's efficiency need to be specify while the property right theory is justified, i.e. technical efficiency or allocative efficiency, or both? Second, as argued by Kao et al. (1995), from the viewpoint of management, both TE and AE concerning the operation management system, basically it takes time to increase the management level. However, it is possible that TE would take more time than AE to be efficient. Because the former requires higher level of technology to obtain maximal output from a given set of inputs, while the latter only need to adjust the allocation of the inputs in optimal proportions, given their respective prices. These may help both operators and policy makers throw light on efficiency improvement process, so as to set up their targets to find a way to enhance overall efficiency.

2. Pricing strategies

Traditionally, when information on each input price and output price are not available, allocative efficiency cannot be estimated. Cases that lead to information on prices being unavailable pose a serious problem for the standard techniques of efficiency measurement, and that alternative pricing strategies influence a firm's profit margin through their effect both on expected profits and on the discount rate applied to those profits' effects that are not taken into account by the standard techniques of efficiency measurement. To solve these two problems, this paper turns to an alternative hyperbolic graph efficiency measurement which was proposed by Fare et al. (2002). This alternative gauges efficiency relative to frontiers that are not conditioned on prices and hence account for the efficiency of different pricing strategies. These techniques are described to analyze how their measures of efficiency differ and how they are related to the profit margins of firms. To illustrate the importance of accounting for price distortion in measuring efficiency, this alternative model is employed to study how differences in pricing strategies affect the profit margin of the firms before and after privatization.

The empirical results implies that perhaps in an attempt to cover the inefficiency-induced losses, both SOE and POE apparently resorted to distorting relative output prices with respect to input prices; the distortion being more pronounced in POE than in its predecessor. Apparently, this alternative technique of efficiency measurement may help both operators and decision-makers to set up their targets to reduce the inefficiency through different pricing strategies. As well, due to that privatization had given a great deal of freedom to the newly-established KKTC, this private enterprise is more flexible in adopting various pricing strategies.

3. Size of transit firm

It is often thought that bigger transit firms (or stations) operate more efficiently than small firms (or stations). From the results of the first essay, that stations of approximately 40-70 vehicles are of optimal size, there is evidence that this is not true. That is, size of transit firm does not necessarily play a large role in the efficiency of the firm.

4. Transport risk

Many public policy efforts seek to identify and eliminate the production inefficiency that prevents simultaneous improvements in both efficiency and transportation safety. Whether these types of public policy initiatives are successful depends on the extent to which such inefficiencies are widespread in transport services, especially in intercity bus services. This study measures the efficiency changes before and after privatization where transport risk as a joint but undesirable output can be reduced with efficiency improved concurrently among a set of stations producing bus services. This may help producers, consumers and policy makers to pay more attention to the overall safety performance of bus transport, so as to meet both business and social goals.

5. Black box

Fare and Grosskopf (2002) indicated that the traditional models for DEA-type performance measurement are based on thinking about production as a “black-box”. Inputs are transformed in this box into outputs. The actual transformation process is generally not modeled explicitly; rather; one simply specifies what enters the box and what exits. This is, in fact, one of the advantages of DEA-it reveals rather than imposes the structure of the transformation process. The network DEA model allows to study the “inside” of the usual black box technology. They accomplish this by providing a very general framework for specifying the inner workings of the black box.

In this study, by explicitly modeling intermediate products, i.e., produced and used services inside the technology, the actual transformation process of bus service reveals. This may help operators, consumers and decision-makers become aware of the whole production and consumption processes as well as the trade-off between efficiency and effectiveness measures, so as to elevate the overall performance of bus transit systems.

9.4 Area for further research

Much as the objectives of this dissertation have been achieved, however, the remaining issue to be resolved in the future is of three aspects. First, incorporating the service area population and car ownership, or even transportation demand as environmental variables may not be enough, since transit performance is thought to be sensitive to the environment in which the system operates (Giuliano, 1981). Some other appropriate economic environmental variables accounting for the changes in efficiency and/or productivity over the study period need to be identified further and thus taken into account. Second, DEA is deterministic and so is plagued by measurement errors in the included variables. Therefore, developing a stochastic model to describe the impact is also a future work.

Another issue to consider is that transit operations are affected by intangible characteristics such as service quality components which have universal applicability on all the operations of a transit system. The effects of this factor on transit performance need to be further investigated by incorporating the intangible spirit of quality of service into the evaluation model, for both theoretical issues and the practical applicability of the model.

REFERENCES

1. Aigner, D. J. and Chu, S. F. "On estimating the industry production function", American Economic Review, 58, pp.826-839, 1968.
2. Aigner, D. J., Lovell, C. A. K. and Schmidt, P. "Formulation and estimation of stochastic frontier production function models", Journal of Econometrics, 6, pp.12-37, 1977.
3. Alexandersson, G., Hulten, S. and Folster, S. "The effects of competition in Swedish local bus services", Journal of Transport Economics and Policy, 32, pp.203-219, 1998.
4. Anderson, S. C. and Fielding, G. L. "US department of transportation", Comparative Analysis of Transit Performance, Washington D.C., Final report, 1992.
5. Banker, R. D., Charmes, A. and Cooper, W. W. "Some models for estimating technical and scale inefficiencies in data envelopment analysis", Management Science, 30, pp.1078-1092,1984.
6. Battese, G. E. and Coelli, T. J. "A model for technical inefficiency effects in a stochastic frontier production function for panel data", Empirical Economics, 20, pp.325-332, 1995.
7. Beasley, J. "Determining teaching and research efficiencies", Journal of the operational research society, 46 (4), pp.441-452, 1995.
8. ————, "Allocating fixed costs and resources via data envelopment analysis", European Journal of Operational Research, 147, pp.198-216, 2003.
9. Berechman, J. and Giuliano, G. "Economies of scale in bus transit: A review of concepts and evidence", Transportation, 12, pp.313-332, 1985.
10. Bhattacharyya, A., Kumbhakar, S. and Bhattacharyya, A. "Ownership structure and cost efficiency: a study of publicly owned passenger-bus transportation companies in India", Journal of Productivity Analysis, 6, pp.47-61, 1995.
11. Boame, A. K. The sources of efficiency change in the Canadian urban transit systems: a data envelopment analysis (DEA) approach, Ph.D. dissertation, Department of Economics, the University of Manitoba, Winnipeg, MB, Canada, 2001.
12. Boardman, A., Vining, A. R. "Ownership and performance in competitive environments: a comparison of the performance of private, mixed, and state-owned enterprises", Journal of Law and Economics, 32, pp.1-33, 1989.
13. Bonnie, J. P., and Putterman, L. Economics of cooperation and the labor-managed economy, Harwood, 1987.

14. Bonnie, J. P., Jones, D. C., and Puterman, L. “Theoretical and empirical studies of producer cooperatives: will ever the Twain meet?”, Journal of Economic Literature, 31(3), pp.1290-1320, 1993.
15. Boubakri, N., Cosset, J. C. “The financial and operating performance of newly privatized firms: evidence from developing countries”, Journal of Finance, 53, pp.1081-1110, 1998.
16. Boycko, Maxim, Andrei, S. and Robert W. V. “A theory of privatization”, Economic Journal, 106, pp. 309-319, 1996.
17. Boyd, G., Tolley, G., and Pang, J. “Plant level productivity, efficiency, and environmental performance of the container glass industry”, Environmental and Resource Economics, 23, pp.29-43, 2001.
18. Button, K. and Costa, A. “Economic efficiency gains from urban public transport regulatory reform: two case studies of changes in Europe”, Regional Science, 33, pp.425-438, 1999.
19. Caves, D. W., Christensen, L. R. and Diewert, W. E. “The economic theory of index numbers and the measurement of input, output and productivity”, Econometrica, 50, pp. 1414-1393, 1982.
20. ——————————————, “The economic theory of index numbers and the measurement of input, output and productivity”, Production Frontiers, Cambridge University Press, Cambridge, 1994.
21. Chambers, R. G., Chung, Y., and Fare, R. “Profit, directional distance functions, and Nerlovian efficiency”, Journal of Optimization Theory and Applications, 98, pp.351-364, 1998.
22. Chang C. C. “The nonparametric risk-adjusted efficiency measurement: an application to Taiwan’s major rural financial intermediaries”, American Journal of Agricultural Economics, 81, pp.902-913, 1999.
23. Chang, K. P. and Kao, P. H. “The relative efficiency of public versus private municipal bus firms: an application of data envelopment analysis”, Journal of Productivity Analysis, 3, pp.67-84, 1992.
24. Chang L. Y. Performance evaluation of privatization on the intercity bus company: a case study of Taiwan Motor Corporation, Master thesis, Department of Transportation and Logistics Engineering, Nation Cha-I University, Taiwan, 2003 (in Chinese).
25. Charnes, A., Cooper, W. W., Lewin, A. Y. and Seiford, L. M. Data Envelopment Analysis: Theory, Methodology, and Application, Kluwer Academic Publishers, Dordrecht, 1994.

26. Charnes, A., Cooper, W. W. and Rhodes, E. "Measuring the efficiency of decision making units", European Journal of Operational Research, pp.429-444, 1978.
27. ———————————————, "Evaluating program and managerial efficiency: an application of data envelopment analysis to program follow through", Management Science, 27(6), 668-697, 1981.
28. Chen, D. J. and Shiau J. W. "A study on the development of DEA model for the aggregate performance evaluation of highway bus industry, Transportation Planning Journal, 23(1), pp.11-40, 1994 (in Chinese).
29. Chen, J. J. and Sun S. "A study on the performance of Taipei joint operation bus system", Proceedings of the Conference on Technology and Management, Taipei, Taiwan, R.O.C, 2001 (in Chinese).
30. Cho, H. J. and Fan C. K. "The performance of Taiwan motor transport company before and after privatization", Journal of the Eastern Asia Society for Transportation Studies, 5, pp.2872-2882, 2003.
31. —————————, "The performance of Taiwan motor transport company before and after privatization", The 5th International Conference of Eastern Asia Society for Transport Studies, Fukuoka, Japan, 2003.
32. —————————, "Evaluating the performance of privatization on regional transit services: a case study", ASCE Journal of Urban Planning and Development, (Accepted April 2004).
33. —————————, "Measuring the risk-adjusted efficiency of Taiwan Motor Transport Company before and after privatization", World Scientific and Engineering Academy and society (WSEAS) International conferences, 2004.
34. Chu, X., Fielding, G. and Lamar, B. "Measuring transit performance using data envelopment analysis", Transportation Research, 26, pp.223-230, 1992.
35. Coelli, T., Prasada Rao, D. S. and Battese, G. E. "An introduction to efficiency and productivity analysis", Kluwer Academic Publishers, Boston, 1998.
36. Coelli, T. J. A guide to DEAP version 2.1: a data envelopment analysis (computer) program, CEPA working papers, 8/96, Dept. of Econometrics, University of New England, Armidale, Australia, 1996.
37. Cook, W. D., Hababou, M., and Tuerter, H. J. H. "Multicomponet efficiency measurement and shared inputs in data envelopment analysis: an application to scales and service performance in bank branches", Journal of Productivity Analysis, 14, pp.209-224, 2000.

38. Cook, W. D., and Kress, M. “Characterizing an equitable allocation of shared costs: a DEA approach”, European Journal of Operational Research, 199, pp.652-661, 1999.
39. Costa, A. “Public transport efficiency and effectiveness: Metro de Madrid”, In K. Button, P. Nijkamp and H. priemus (eds)”Transport Networks in Europe: Concepts, Analysis and Policies. Elgar,Cheltenham, pp.248-264, 1998.
40. Cowie, J. and Asenova, D. “Organisation form, scale effects and efficiency in the British bus industry”, Transportation, 26, pp.231-248, 1999.
41. Cowie J. “Acquisition, efficiency and scale economies: An analysis of the British bus industry”, Transport Reviews, 22(2), pp.147-157, 2002.
42. Dajani, J. S., and Gilbert, G. “Measuring the performance of transit systems”, Transportation Planning and Technology, 4, pp.97-103, 1978.
43. Dalen, D. M. and Gomez-Lobo, A.“Yardsticks on the road: regulatory contracts and cost efficiency in the Norwegian Bus Industry”, Transportation, 30, pp. 371-386, 2003.
44. De Borger, B. “The economic environment and public enterprise behaviour: Belgian railroads, 1950-1986”, Economica, 60, pp.443-463, 1993.
45. De Borger, B., Kerstens, K. and Costa, A. “Public transit performance: What does one learn from frontier studies”, Transport Reviews, 22, pp.1-38, 2002.
46. Debreu, G. “The Coefficient of Resource Utilization”, Econometrica, 19, pp. 273-292, 1951.
47. Dewenter, K.L., Malatesta, P.H. “Public offerings of state-owned and privately-owned enterprises: An international comparison”, Journal of Finance, 52, pp.1659-1679, 1997.
48. ——————————, “State-owned and privately-owned firms: an empirical analysis of profitability, leverage, and labor intensity”, American Economic Review, 91, pp.320-334, 2001.
49. Diez-Ticio, A. and Mancebon, M. “The efficiency of the Spanish police service: an application of the multiactivity DEA model”, Applied Economics, 34, pp.351-362, 2002.
50. D’Souza, J., Megginson, W. L. “The financial and operating performance of newly privatized firms in the 1990’s”, Journal of Finance, 54, pp.1396-1438, 1999.
51. Fare, R., Grabowski, R., Grosskopf, S. and Kraft, S. “Efficiency of a fixed but allocatable input: a non-parametric approach”, Economics Letters, 56, pp. 93-187, 1997.
52. Fare, R. and Grosskopf, S. “Shadow pricing of good and bad commodities”, American Journal of Agricultural Economics, 80, 3, pp.584-590, 1998.
53. ——————————, “Network DEA”, Socio-Economic Planning Sciences, 34, pp.35-49, 2002.

54. Fare, R. Grosskopf, S. and Lovell, C. A. K. The Measurement of Efficiency of Production. Kluwer Acadernic Publibers, Boston, 1985.

55. ——————————————, Production Frontiers, Cambridge: Cambridge University Press, 1994.

56. Fare, R., Grosskofp, S., Lovell, C. A. K. and Pasurka, C. "Multilateral productivity comparisons when some outputs are undesirable: a nonparametric approach", Review of Economics and Statistics, 71, 1, pp. 90-98, 1989.

57. Fare, R., Grosskopf, S. and Weber, W. (1997), "The effect of risk-based capital requirements on profit efficiency in banking", Discussion Paper Series, Department of Economics, Southern Illinios University at Carbondale, pp.97-112, 1997.

58. Fare, R., Grosskopf, S. and Zaim, O. "Hyperbolic efficiency and return to the dollar", European Journal of Operational Research, 136, pp.671-679, 2002.

59. Fare, R. and Primont, D. Multi-Output Production and Duality: Theory and Applications, Kluwer Academic Publishers, Boston, 1995.

60. Farrell, M. J. "The measurement of productive efficiency", Journal of Royal Statistical Society A, 120, pp.253-281, 1957.

61. Fazioli, R., Filippini, M.and Prioni, P. "Cost-structure and efficiency of local public transport: the case of Emilia Romagna bus companies", International Journal of Transport Economics, 20, pp.305-324, 1993.

62. Fielding, G. J. Managing public transit strategically, Jossey-Bas, Inc., San Francisco, 1987.

63. Fried, H. O., Lovell C. A. K., Schmidt S. S. and Yaisawarng S. "Accounting for environmental effects and statistical noise in data envelopment analysis", Journal of Productivity Analysis, 17, pp.157-174, 2002.

64. Gathon, H. J. "Indicators of partial productivity and technical efficiency in the European urban transit sector", Annals of Public and Cooperative Economics, 60, pp.43-59, 1989.

65. Georgeson-Roegen, N. "The aggregate linear production function and its applications to Von Neumann's economic model", In Koopmans, T. (Ed.), Activity Analysis of Production and Allocation, Wiley, New York, 1951.

66. Gillen, D. and Lall, A. "Developing measures of airport productivity and performance: an application of data envelopment analysis", Transportation Research E, 33(4), pp.261-273, 1997.

67. Giuliano, G. "Effect of environmental factors on the efficiency of public transit service", Transportation Research Record, 797, TRB, National Research Council, Washington, D. C., pp. 11-16, 1981.

68. Golany, B. Phhllips, F. Y. and Rousseau, J. J. "Models for improved effectiveness based on DEA efficiency results", IIE Transactions, 25, pp.2-10, 1993.
69. Golany, B. and Tamir, E. "Evaluation efficiency-effectiveness-equality trade-offs: a data envelopment analysis approach", Management Science, 41,pp.1172-1184, 1995.
70. Gomez-Ibanez, J. A. and Meyer, J. R. "Privatizing and deregulating local public services: Lessons from Britain's buses", Journal of the American Planning Association, 56, pp.9-21, 1990.
71. ————————————, Going private-the international experience with privatization, The Brookings Institution, Washington, D.C., 1993.
72. Greene, W. "Frontier production functions", Handbook of Applied Econometrics, In Pesaran, M. H. and Wickens, M. R. (eds), 2, pp.81-166, 1997.
73. Grosskopf, S. "Statistical inference and non-parametric efficiency: a selective survey", Journal of Productivity Analysis, 7, pp.161-176, 1996.
74. Harper, J. T. "The performance of privatized firms in the Czech republic", Journal of Banking & Finance, 26, pp.621-649, 2002.
75. Hensher, D. A. and Daniels, R."Productivity measurement in the urban bus sector", Transport policy, pp.179-197, 1995.
76. Hibbs J. Bus and Coach Management, Chapman and Hall, London, pp.112, 1985.
77. Hooper, P. G. and Hensher D. A. "Measuring total factor productivity of airports-an index number approach", Transportation Research E, 33 (4), pp. 249-259, 1997.
78. Hughes, J. P. "Measuring efficiency when competitive prices aggregate differences in product quality and risk", Research in Economics, 53, 47-76, 1999.
79. Institute of Transportation, Ministry of Transportation and Communications, The third Taiwan area integrated transportation system planning study, 1999, Taipei, Taiwan (in Chinese).
80. Jorgensen F., Pedersen P. A. and Volden R. " Estimating the inefficiency in the Norwegian bus industry form Stochastic cost frontier models", Transportation, 24, pp.421-433, 1997.
81. Karlaftis, M.G. "Investigating transit production and performance: a programming approach", Transportation Research A,37, pp.225-240, 2003.
82. ——————, "A DEA approach for evaluating the efficiency and effectiveness of urban transit systems", European Journal of Operational Research, 152, pp.354-364, 2004.

83. Kao, C., Chen, L. H., Wang, T. Y., Kuo, S. and Horng, S. D. "Productivity improvement: efficiency approach vs effectiveness approach", Omega International Journal Management Science, 23, 2, pp.197-204, 1995.
84. Karlaftis, M. G. and McCarthy, P. S. "The effect of privatization on public transit costs", Journal of Regulatory Economics, 16, pp.27-43, 1999.
85. Karlaftis, M. G. and Sinha, K. C. "Effect of operating subsides in the paratransit sector", Transportation Research Record, 1571, National Research Council, Washington, D. C., pp.75-80, 1997.
86. Kerstens, K. "Technical efficiency measurement and explanation of French urban transit companies", Transportation Research, 30A, pp.431-452, 1996.
87. ————, "Decomposing technical efficiency and effectiveness of French urban transport", Annales d'Economie et de Statistique, 54, pp.129-155, 1999.
88. Kerstens, K. and Vanden Eeckaut, P. "The economic cost of subsidy-induced technical inefficiency: a methodological postscript" International Journal of Transport Economics, 22, pp.225-229, 1995.
89. Koopmans, T. C. "An analysis of production as an efficiency combination of activities, in T. C. Koopmans (Ed.)", Activity analysis of production and allocation, Cowles Commission for Research in Economics, Monograph No.13, Wiley, New York, 1951.
90. Labrecque H. J., Measurement of efficiency in urban mass transit via a Data Envelopment Analysis, Master thesis, Department of Economic, the University of New Brunswick, 1996.
91. Levaggi, R. "Parametric and non-parametric approach to efficiency: the case of urban transport in Italy", Studi Economici, 49, pp.67-88, 1994.
92. Lijesen, M. "Analyzing cost structures of public sector activities, with an application to regional public transport", Performance Budgeting: a Perspective on Modelling and Strategic Planning in the Public Sector in Holland. G. B. K. de Graan and F. G. Volmer eds., Eburon, Delft, pp. 178-187, 1998.
93. Lothgren, M., and Tambour, M. "Productivity and customer satisfaction in Swedish pharmacies: A DEA network model", European Journal of Operational Research, 115, pp.449-458, 1999.
94. Lovell, C. A. K., Production frontiers and economic efficiency: the measurement of productive efficiency, Chapter 1 and 3, Oxford University Press, 1993.
95. Lyons, D. M. "Performance measurement in urban transit: a comparative analysis of single and partial measures of transit performance", Transportation Research A, 31, pp. 69, 1997.

96. Mackie, P., Preston, J. and Nash, C. "Bus deregulation: ten years on", Transport Reviews, 15, pp.229-251, 1995.
97. Mar Molinero, C. "On the joint determination of efficiencies in a data envelopment context", Journal of the Operational Research Society, 47, pp.1273-1279, 1996.
98. Mar Molinero, C. and Tsai, P. F. "Some mathematical properties of a DEA model for the joint determination of efficiencies", Journal of the Operational Research Society, 48, pp.51-56, 1997.
99. Matas A. and Raymond, J. L. "Technical characteristics and efficiency of urban bus companies: the case of Spain", Transportation, 25, pp. 243-263, 1998.
100. McCrosson D. F. "Choosing performance indicators for small transit systems", Journal of Transportation Engineering, 48, pp.26-30, 1978.
101. Meeusen, W. and van den Broeck, J. "Efficiency estimation from cobb-douglas production functions with composed error", International Economic Review, 18, pp.435-444, 1997.
102. Megginson, W. L., Nash, R. C., Netter, J. M. and Poulsen, A. B. "The choice of privatization method: an empirical analysis", Working Paper, university of Georgia. 2000a.
103. Megginson, W. L., Nash, R. C., Netter, J. M. and Schwartz, A. L. "The long-run retrun to investors in share issue privatizations", Financial Management, 2000b.
104. Megginson, W. L., Nash, R. C. and van Randenborgh, M. "The finacial and operating performance of newly privatized firms: An international empirical analysis", Journal of Finance, 49, pp.403-452, 1994.
105. Megginson, W. L. and Netter, J. M. "From State to Market: A Survey of Empirical studies on Privatization", Journal of Economic Literature, 39, pp. 321-389, 2001.
106. Mester, L. J. "A study of bank efficiency taking into account risk-preferences", Journal of Bank and Finance, 20, pp.45-1025, 1996.
107. Miller, D. R., Lathrop, G. T. and Stuart, D. R. Simplified guidelines for evaluating transit service in small urban areas, Transportation Research Board, National Research Council, Washington, D. C., 1984.
108. Mulley, C. and Wright, M. "Management buy-outs and the privatization of National Bus", Fiscal Studies, August, pp.1-23, 1986.
109. Nakanishi, Y. J. and Norsworthy, J. R. "Assessing efficiency of transit service", IEEE International Engineering Management Society Conference, pp.133-140, Albuquerque, New Mexico, 2000.

110. National Federation of Bus Passenger Transportation of the Republic of China, Annual Statistical Reports, Taipei, Taiwan, R.O.C., 2002.

111. Nolan, J. F. "Determinants of productive efficiency in urban transit", Logistic and Transportation Review, 32(3), pp.319-342, 1996.

112. Nolan, J. F., Ritchie, P. C. and Rowcroft, J. E. "Identifying and measuring public policy goals: ISTEA and the US bus transit industry", Journal of Economic Behavior and Organization, 48, pp.291-304, 2002.

113. Obeng, K. "The economic cost of subsidy-induced technical inefficiency", International Journal of Transport Economics, 21, pp.3-20, 1994.

114. Obeng, K., Assar, N. and Benjamin, J. "Total factor productivity in transit systems: 1983-1988", Transportation Research A, 26(6), pp. 447-455, 1992.

115. Obeng, K. and Sakano R. "Total factor productivity decomposition, input price inefficiencies, and public transit systems", Transportation Research E, 38, pp.19-36, 2002.

116. Odeck, J. "Ownership, scale effects and efficiency of Norwegian bus operators: empirical evidence", International Journal of Transport Economics, XXX, 3, pp.305-325, 2003.

117. Odeck, J. and Alkadi A. "Evaluating efficiency in the Norwegian bus industry using data envelopment analysis", Transportation, 28, pp.221-232, 2001.

118. Parker, D. "The performance of BAA before and after privatization: a DEA study", Journal of Transport Economics and Policy, 33, 2, pp.133-46, 1999.

119. Perelman, S. and Thiry, B. "Measuring the performance of public transport companies", Annals of Public and Cooperative Economics, 60(1), pp. 3-8, 1989.

120. Pina, V. and Torres, L. "Analysis of the efficiency of local government services delivery. An application to urban public transport", Transportation Research A, 35, pp.929-944, 2001.

121. Robbins, D. K. and White P. R. "The experience of express coach deregulation in great Briton", Transportation, 13, pp.359-384, 1986.

122. Roy, Jean-P. "Performance indicators of the transport sector", in Canadian transportation research forum: transport gateways and trade corridors, Proceedings of the 31st Annual Conference, Winnipeg, MB, Canada, May, 2, pp. 719-733, 1996.

123. Sakano, R., Obeng, K. "Re-examination of inefficiencies in urban transit systems: a stochastic frontier approach", Logistics and Transportation Review, 31, pp.377-392, 1995.

124. Sakano, R., Obeng, K. and Azam, G. “Subsidies and inefficiency: stochastic frontier approach”, Contemporary Economic Policy, 15, pp.113-127, 1997.

125. Shephard, R. W. Theory of Cost and Production Functions, Princeton University Press, Princeton, 1970.

126. Small, K. A. “Urban Transportation Economics”, Harwood Academic Publishers, Philadelphia, U.S.A. 1992.

127. Stopher, P. R., and Meyburg Arnim, H. Transportation Systems Evaluation, Lexington, Mass, 1976.

128. Sueyoshi, T. “Privatization of Nippon Telegraph and Telephone: was it a good policy decision”, European Journal of Operation Research, 107, pp.45-61, 1998.

129. Talley, W. K., and Anderson P. P. “Effectiveness and efficiency in transit performance: a theoretical perspective”, Transportation Research A, 15(6), pp.431-436, 1981.

130. Taskin, F., and Zaim, O. “Searching for Kuznets curve in environmental efficiency using Kernel estimation”, Economics Letters, 68, pp.217-223, 2000.

131. Thanassoulis, E. “A data envelopment analysis approach to clustering operating units for resource allocation purposes”, Omega, 24, pp.463-476, 1996.

132. ————————, “Estimating efficient marginal resource levels using data envelpment analysis”, Journal of Cost Analysis, pp. 29-52,1998.

133. Thiry, B. and Tulkens, H. “Allowing for inefficiency in parametric estimation of production functions for urban transit firms”, Journal of Productivity Analysis, 3, pp.45-65, 1992.

134. Tomazinis, A.R., Productivity, efficiency, and quality in urban transportation systems, Lexington, Mass, 1975.

135. Tomkins, C. and Green, R. “An experiment in the use of data envelopment analysis for evaluating the efficiency of UK university departments of accounting”, Financial Accountability& Management, 4, 2, pp.147-164, 1988.

136. Tone K., and Sawada, T. “An efficiency analysis of public vs. private bus transportation enterprises”, Operational Research ’90 ed. Bradley, H., pp. 357-365, Pergamon, New York, 1990.

137. Tsai, P. F. and Mar Molinero, C. “The joint determination of efficiencies in DEA: an application to the UK health service”, Department of Management, Discussion Paper, University of Southampton, 1998.

138. ————————————, “A variable returns to scale data envelopment analysis model for the joint determination of efficiencies with an example of the UK health service”, European Journal of Operational Research, 141, pp.21-38, 2002.

139. US Department of Transportation, Urban Mass Transportation Administration, Proc. of the 1st Nat. on Conf. on Transit performance, U.S. Government Printing Office, Washington, D.C., 1978.

140. Viton, P. "The question of efficiency in urban bus transportation", Journal of Regional Science, 26(3), pp. 499-513, 1986.

141. ———, "Consolidations of scale and scope in urban transit", Regional Science and Urban Economics, 22, pp.25-49, 1992.

142. ———, "Changes in multi-mode transit efficiency, 1988-1992", working paper, The Ohio State University, 1995.

143. ———, "Technical efficiency in multimode bus transit: a production frontier analysis", Transportation Research B, 31, pp.23-39, 1997.

144. ———, "Changes in multimode bus transit efficiency, 1988-1992", Transportation, 25, pp.1-21, 1998.

145. White, P. "The experience of bus and coach deregulation in Britain and in other countries", International Journal of Transport Economics, XXIV, 35-52, 1997.

146. Wright, M., Dobson, P., Thompson, S. and Robbie, K. "How well does privatization achieve government objectives? The case of bus buy-outs", International Journal of Transport Economics, XIX, pp.258-285, 1992.

147. Wright, M. and Mulley, C. "Early experiences from the privatization of National Bus", Annual Conference of Transport Research Group, University of Newcastle upon Tyne, 1989.

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台灣省道路交通安全督導協調會報 **執行秘書、委員**（78.7~84.3）
台灣省政府汽車肇事覆議鑑定委員會 **委員、主任委員**（78.11~84.3）
台灣省政府改善停車問題專案小組 **執行秘書、副召集人** (83.3~86.4)
高雄市港建設合一協調委員會 **委員** （84.7~87.7）
唐榮鐵工廠股份有限公司 **董事** （84.7~88.7）
台灣省政府國家賠償事件處理小組 **委員** （86.7~迄今）
台北市政府捷運淡水線初勘委員會 **委員** （86.10~86.12）
考試院八十七年交通事業鐵路人員升資考試 **典試委員** （87.4~87.6）

專　　長：運輸規劃與管理、鐵公路工程與管理、港灣及棧埠工程與管理、旅遊觀光、道路交通安全與管理

Publication Lists

A-1. Journal Papers

1. Cho, H. J. and Fan, C. K. “Evaluating the performance of privatization on regional transit services: a case study”, ASCE journal of Urban Planning and Development, (SSCI, SCI, EI,), Accepted April 2004.
2. Cho, H. J. and Fan, C. K. “The performance of Taiwan Motor Transport Company before and after privatization”, Journal of the Eastern Asia Society for Transportation Studies, 5, pp.2872-2882, 2003.
3. Cho, H. J. and Fan, C. K. “Measuring the risk-adjusted efficiency of Taiwan Motor Transport Company before and after privatization”, Journal of WSEAS Transaction on Mathematics, Issue 1, Vol. 3, pp. 96-101, 2004.

A-2. Proceeding Paper

1. Cho, Hsun-Jung and Chih-Ku Fan “A Dynamical System Approach to The Simulation of Coach Passanger Variation”, Advances in Systems Theory, Mathematical Methods and Applications, Edited by Alexander Zemliak and Nikos E. Mastorakis, WSEAS Press, pp. 123-128, 2002.

B. Conference Papers

1. Cho. H. J. and Fan, C. K. “The performance of Taiwan Motor Transport Company before and after privatization”, The 5th International Conference of Eastern Asia Society for Transport Studies, Fukuoka, Japan, 2003.
2. Cho, H. J. and Fan, C. K. “Measuring the risk-adjusted efficiency of Taiwan Motor Transport Company before and after privatization”, World Scientific and Engineering Academy and Society (WSEAS) International Conferences, 2004.